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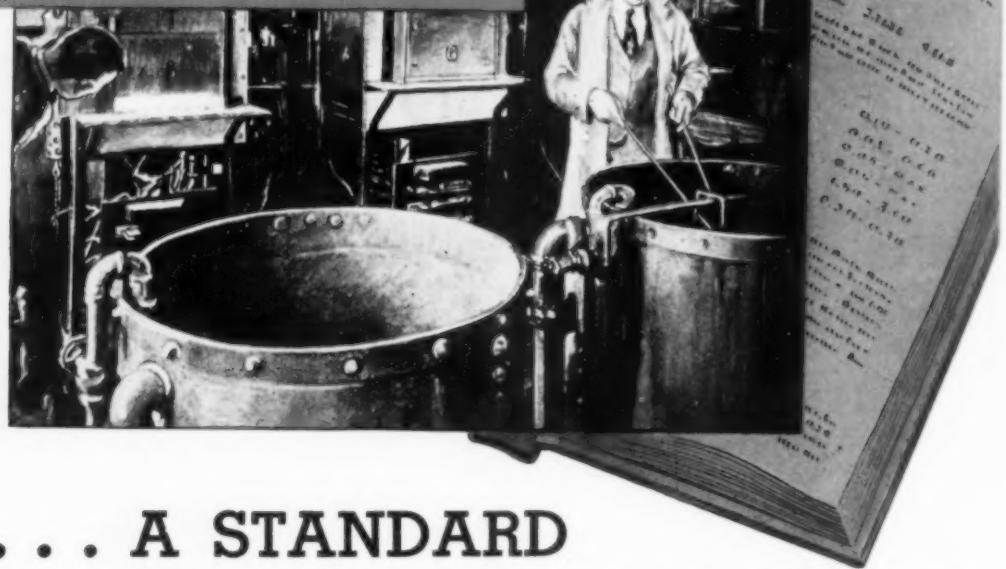
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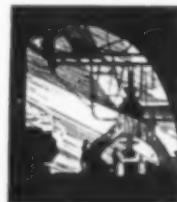
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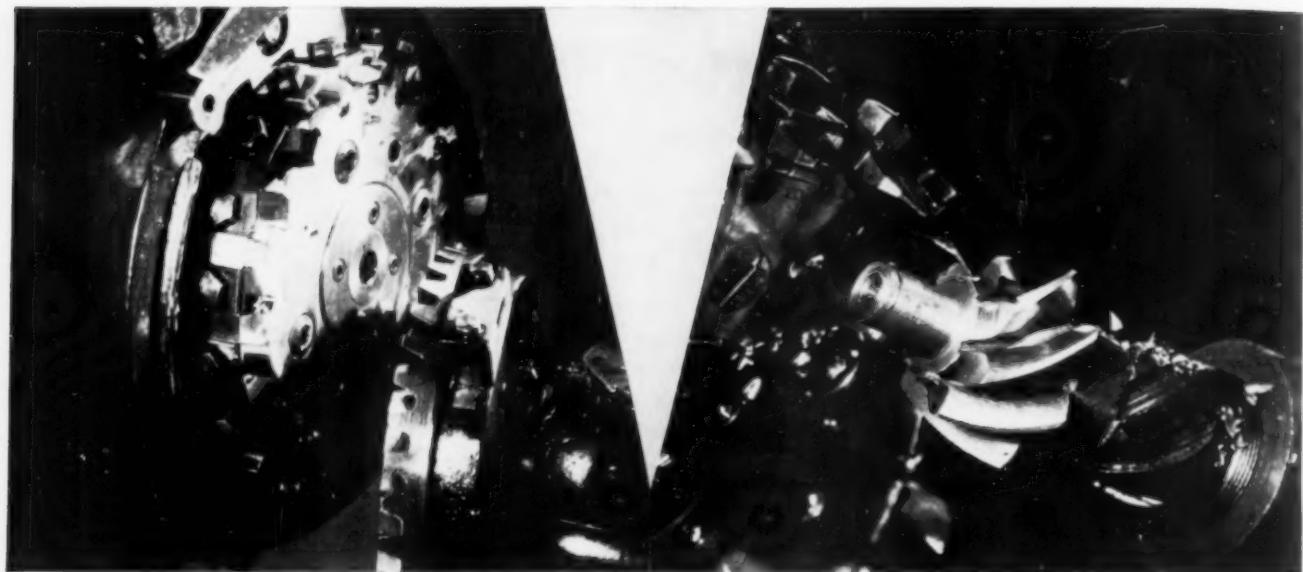
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Ernest E. Thum, Editor

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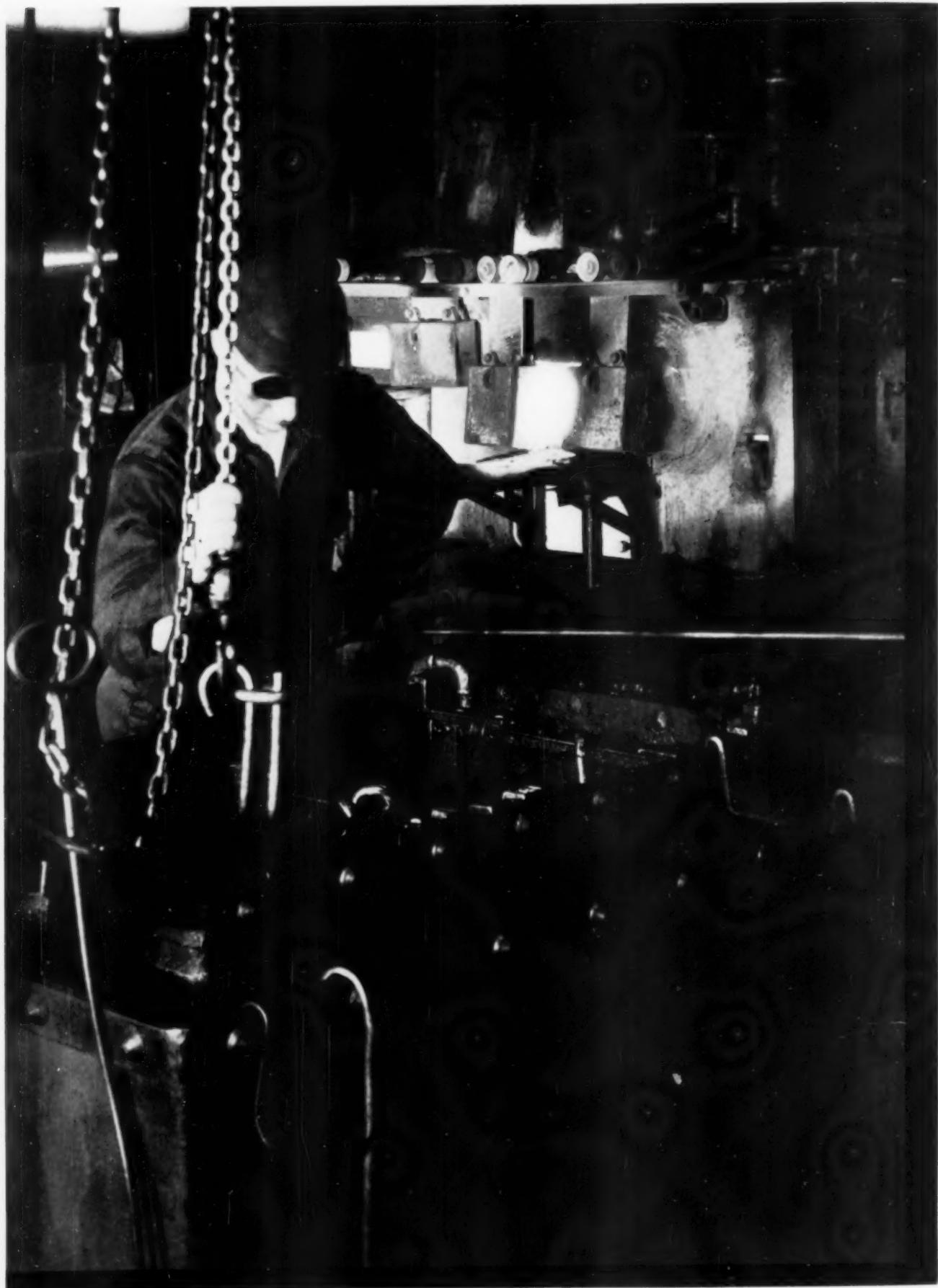
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Photo by Margaret Bourke-White for Ludlum Steel Co.



The Hardener

FACTORS AFFECTING THE INHERENT HARDENABILITY OF STEEL

Edgar C. Bain
Campbell Memorial Lecture
1932

ONLY the briefest abstract of the first portion of Dr. Bain's lecture can be given here. His discussion of the two most important factors, grain size and oxygen content, will occupy most of the available space.

In the introduction, Dr. Bain states the problem: That steels of similar carbon content and of less than 1% total alloying elements, harden quite differently, mass, shape and quenching conditions being the same. Some will be hardened to the center, others only in a shallow zone, still others may even have soft spots on the surface.

Since hardenability is associated with the decomposition of austenite, Dr. Bain first presented data from previous papers and from studies by his colleague, E. S. Davenport, on the time-lag before this reaction reaches measurable speed and the time required for substantial transformation (both at various constant temperatures). "A high carbon steel must be cooled through the Ar' range, 600° to 500° C., at a velocity somewhere in the vicinity of 100° C. per sec., if it is to escape some transformation to nodular fine-pearlite and instead

to form martensite in the Ar" region, below about 150° C. The sole task of a quenching medium is to abstract heat with sufficient rapidity, and the real function of alloying elements which induce deep hardening is merely that of slowing up the reaction in the upper range."

To emphasize these points, the first chart shows the relation of temperature at which transformation starts and the rate at which heat is abstracted. It applies to commercial sizes of steel; the exterior may cool according to curve A and be hard, whereas the center may cool according to curve B and be soft. The curve PQ is characteristic for the steel. It could be shifted, in its relation to curves A and E, either to the left upward, or to the right downward, so the fixed quenching rate would cut through the corner QPS (when the steel would be shallow hardening) or miss point P altogether (when the steel would be deep hardening). An increase in manganese could easily shift the curves in this manner.

Evidence was cited to show that "the rate at which austenite *prepares* to transform at the Ar' range of maximum activity controls the hardenability of a steel. Steels of lower true critical point (A₁) will, in general, have lower rates of reaction and tend to transform at lower temperature and to form harder constituents than steels of high critical point.

"A grain of austenite in transforming soon develops a high rate of reaction, even though it lags at first. As soon as about a third of

the grain is transformed the velocity of reaction falls off rapidly and for this reason it is possible to find in the intermediate layers of a quenched bar of steel many of the original grains of austenite, which are partly martensitic and partly fine-pearlitic.

"On this basis the hardenability of steels is not a matter of static properties, but rather is concerned solely with rates."

External Factors and Inherent Factors

In this category Dr. Bain places *quenching temperature*, which obviously influences the rate of cooling. "The time required for any small portion of the quenched piece to pass through the important temperature zone is the less the higher the quenching temperature." *Structure prior to heating* is of importance when the time at heat is insufficient to dissolve excess constituent and then to produce uniform austenite just before quenching.

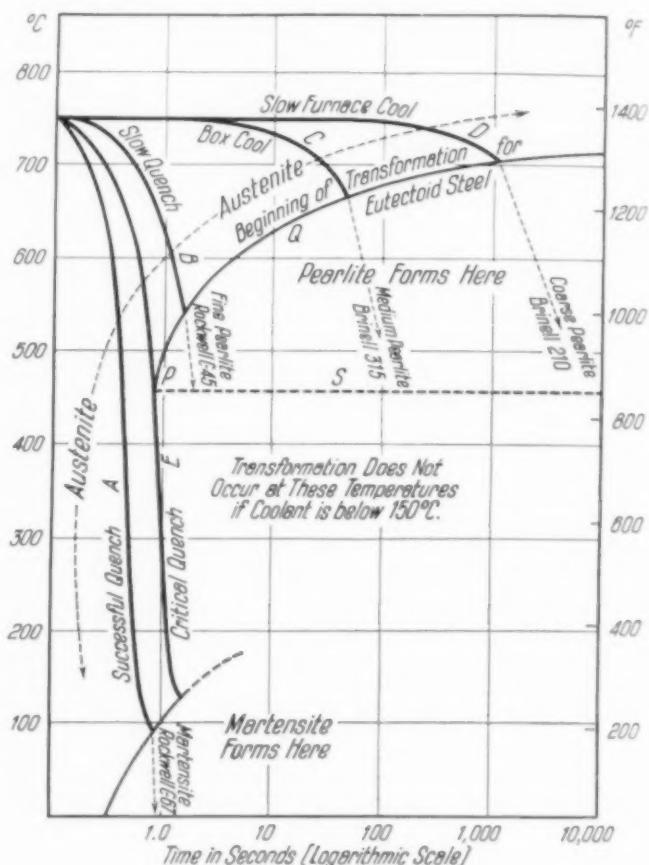
Austenitic Grain Size— "A fine grain size was a usual accompaniment to the carburized steel described by McQuaid and Ehn as hardening with soft spots. It occurred to us that fine austenitic grain size may be a cause, rather than a mere symptom, of the rapid transformation rate responsible for low hardening capacity." To test this hypothesis, minute specimens of steel were coarsened by heating to various temperatures. These were quickly cooled to 705° C., held there 75 sec., quenched, and then examined under the microscope to determine the amount of austenite remaining.

Results are tabulated and indicate that the coarse-grained steel transforms more slowly,

Sample	Coarsened At	Grains per Sq. In. (100 Diag.)	Austenite After 75 Sec. at 705°C.
A	790°C	130	none
B	840	45	none
C	870	22	10%
D	900	16	45
E	950	12	80
F	1010	7	100

and therefore should harden better and deeper — which actual quenching tests proved. Coarsened specimens also have lower recalescence points, characteristic of a deeper hardening steel. Lastly, the coarse-grained specimens were refined, and the fine-grained ones coarsened and

Approximate Relationship Between Cooling Rate and Temperature at Which Austenite Begins to Transform. If quenching curve passes to the left of point P, hard martensitic structure results; if it cuts through tip of angle QPS, soft spots or areas of fine pearlite are found in the quenched sample



the tests repeated. "Substantially the same effect of grain size is shown, indicating that no permanent effect is imparted by a grain size inheritance or otherwise. It may be concluded that grain size in the austenite, prior to transformation, so affects the transformation characteristics of the steel as a whole that coarse-grained steel is essentially a deep hardening steel of slow reaction characteristics, while fine-grained steel is a shallow hardening steel of high reaction speed."

An important section of the lecture discusses the inherent effect of various elements in the composition. Dr. Bain distinguishes between the primary effects of an element, which result from their effect upon the solid solution austenite, and the secondary effects, such as the influence on annealed carbide particle size and the austenite grain growth. Secondary effects of an element may obscure the primary effects, but "among elements contrib-

uting to deep hardening we may include nickel, manganese, chromium, silicon, and aluminum. When present at least to the extent of a few per cent, cobalt, tungsten, vanadium, and probably molybdenum are accelerators of reaction rate and contribute to shallow hardening." The latter group all restrict grain growth so sharply that their primary effect is not known precisely.

Oxygen has long been blamed for vagaries in hardenability, and it is Dr. Bain's belief that its influence is very profound, in spite of its relatively low solubility in austenite. The main difference between oxygen and the other elements which are alloyed with steel is that the dissolved oxygen content is so largely dependent upon the concentration of other elements, for example, aluminum or silicon. He discusses the effect of dissolved oxygen and the normality-abnormality phenomenon under one heading, since it seemed impossible to separate them. (From this point on the phraseology is Dr. Bain's.)

The Essence of Normality

The essentials of the McQuaid-Ehn test are about as follows:

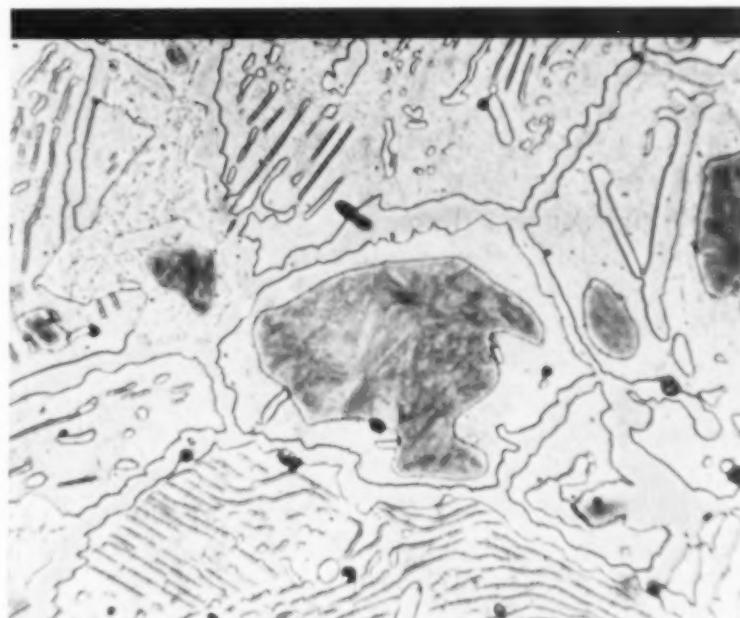
1. The steel is pack-carburized so that a distinctly hyper-eutectoid surface layer is developed.

2. The carburized steel is then cooled down to about 620° C. at a suitable definitely controlled rate, after which it may be cooled as convenient — even quenched. The rate once selected must not vary for the several runs of the comparison.

The resulting structures vary from one steel to another with extremes somewhat as follows: *Normal* — Thin, smooth carbide envelopes entirely contiguous with the finer lamellar pearlite. *Abnormal* — Thick carbide envelopes, with coarse pearlite, if any, broadly separated from the network by a wide band of ferrite; usually the carbide is somewhat spheroidized — even the network may be broken with large carbide lumps.

It has been suggested that the ferrite band between the carbide envelope and the coarse pearlite area forms after the pearlite has origi-

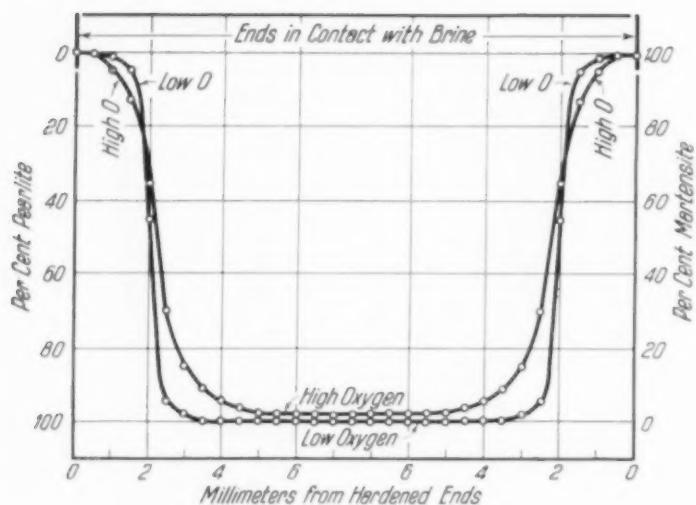
nally filled the grain. This seemed doubtful, so samples were quenched during the progress of transformation. In the first was found the carbide envelope just formed, the remainder of the grain being still wholly austenitic as quenched. From this point the real differentiation begins, although even here the carbide envelope is often thin in the normal or deep hardening steel and thicker in the abnormal shallow-hardening steel, indicating the supersaturation of austenite in the sluggish deep-hardening steel. But in the photograph is shown the progress of the reaction made in the next few minutes. A rim of pure ferrite now separates the carbide envelope from the unchanged austenite (martensite as photographed) and the eutectoid carbon has clearly migrated from the austenite through the ever-widening ferrite band to attach itself to the carbide envelope.



Abnormal Steel Quenched While Centers of Grains Were Still a Solid Solution. Ferrite layers bordering cementite network already are evident. 1000 diameters

In the normal steel, lamellar pearlite is formed immediately the first particle of ferrite is rejected and there is no divorce of cementite and pearlite.

We offer here an explanation of this variation in terms of rates: The diffusivity, i. e., rate of diffusion, of carbon in ferrite increases tremendously with temperature. Furthermore, just below the true A_1 point ferrite forms from



Small Cylinders of Synthetic Low-Oxygen and High-Oxygen Steels Were Carburized, Inserted in Disks of Stainless Steel, Heated to Dissolve Carbide, Cooled to Form Cementite Network, and Quenched in Brine. Exposed ends were fully hardened; central portions were soft. Oxygen does not seem to affect hardening capacity markedly

Grossmann that oxygen-free carburization produces a more normal appearing structure than pack carburizing.

We have therefore corroborated the belief that oxygen is the outstanding common element contributing to abnormality in ordinary low carbon steels, provided steels of extremely fine grain are excluded.

There has been some discussion about the normality of "pure" iron-carbon alloys. "Pure" iron is such a vague designation that it seemed best to test a variety of pure irons from widely different sources, with the assumption that whatever impurities were found in the one were probably not the adulterants of the other.

All these pure irons developed abnormal structure in pack carburizing and five varieties showed pronounced abnormality in oxygen-free carburizing. But one iron, carburized in pure hydrogen and hydrocarbon, was almost entirely normal and possessed an extremely coarse grain size. This iron was produced by Dr. Cioffi from ingot iron by heating it in moist hydrogen for 18 hr. at about 1500° C. Now whether or not this treatment succeeds in producing a hydrogen alloy or merely a really oxygen-free alloy is open to question. The latter is probably true regardless of the former. In any event the pure iron study permits drawing the following conclusions:

1. To secure a normal structure with pack-carburizing requires the presence of some alloying elements of the deep hardening type.

2. Pure oxygen-free iron (perhaps with hydrogen in solution) is normal. Obviously this implies oxygen-free carburizing.

Houdremont has stated in METAL PROGRESS for May that pure iron is abnormal and suggests that any elements which lower the transformation temperature make for normality; presumably he used the standard test involving pack-carburizing and was therefore dealing with high-oxygen iron, regardless of his starting material. It may be interesting to discover the effect of oxygen upon the true lower critical.

austenite more and more slowly with higher temperature. This rate limits the rate of possible broadening of the ferrite rim just inside the carbide envelope.

To produce an abnormal structure, carbide must diffuse more rapidly through ferrite than the ferrite is formed in the rim just inside the carbide network; otherwise simultaneous ferrite and carbide rejection, i. e., pearlite formation, will result. Hence an abnormal structure requires (1) a steel with sufficient transforming rate to prevent under-cooling to temperatures of slow carbide migration, and (2) a carbon diffusivity at this high transformation temperature sufficient to prevent pearlite formation.

An abnormal steel, then, is one of the fast-reacting type but of peculiarly high carbon diffusion rate near but below the true critical point. With the major requirements for abnormal behavior in mind, let us now turn to oxygen itself.

Iron, Carbon, and Dissolved Oxygen

Grossmann and others have shown that during pack carburization, with the CO-generating type of carburizers, oxygen is fed into the steel along with the carbon. On the other hand, it is inconceivable that pure hydrocarbons and hydrogen could introduce oxygen into a steel. We have therefore used pack carburization as a means of manufacturing high-oxygen steel, and to secure low-oxygen steel we have employed hydrocarbon carburization. On some fifty steels carburized by the two methods no exception was found to the rule suggested by

For comparable specimens, low and high in oxygen, with the other elements constant, steels were prepared from low-carbon irons by the two methods of carburizing. Thin strips were carburized throughout the section to about 1.30% carbon. A very pure electrolytic iron (except for oxygen) was used for one comparison; a 0.40% manganese effervescent 0.06% carbon steel was employed for another comparison to represent a commercial analysis.

In both steels the A_1 , range was found to be about 5° C. lower in the oxygen-rich material.

Oxygen, then, is an element which, as dissolved, lowers the true critical point, A_1 , and at the same time provides the high reaction rate and high carbon diffusivity responsible for abnormality. The next step would seem to be the comparison of our synthetic high and low oxygen steels as to relative hardenability.

We were led to assume that dissolved oxygen would strongly contribute to shallow hardening, but to date we have been unable to prove this point. Experimentation has been carried out by preparing high-carbon steels from small cylinders of very pure electrolytic iron. Half the cylinders were pack-carburized and half were hydrogen-treated and likewise carburized but in oxygen-free hydrocarbon gas. Various low metalloid steel wires were likewise carburized, and all were tested for depth of hardening. The greatest difficulty was encountered in securing similar austenitic grain size and the results therefore are not absolutely final. The figure on page 20 shows the relative pro-

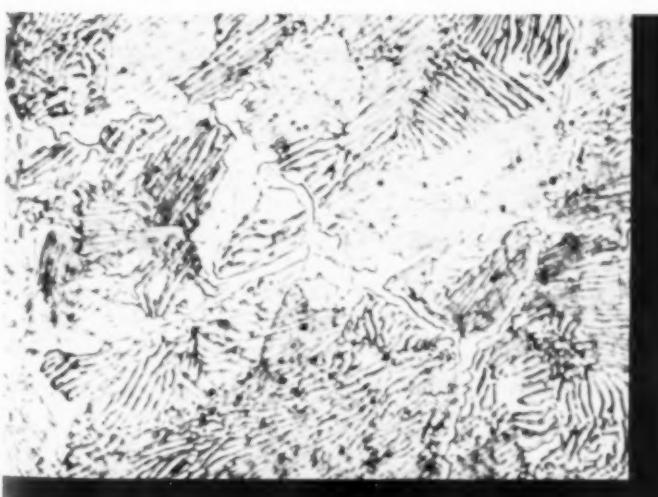
portion of martensite and nodular fine-pearlite in the specimens from end to end. The chart is an average and is representative of all the pure iron-carbon alloys examined.

Perhaps the most that may be said is that dissolved oxygen does not affect hardening capacity markedly; it favors the formation of some martensite but not the complete prevention of some small amount of transformation to fine pearlite. These synthetic pure iron-carbon alloys harden much less deeply than even the most shallow hardening commercial high-carbon steels, and we are led to believe that possibly no steel could show lower hardening capacity than an uncoarsened pure Fe-C alloy.

We conclude then that the ferrite-rim type of abnormality is the particular contribution of dissolved oxygen, which, on the other hand, does not itself contribute significantly toward shallow hardening.

The case for inherent grain size as a major influence upon hardenability grows increasingly strong, and it should be remembered that McQuaid and Ehn found that in most cases abnormality accompanied small grains even in their carburizing steels. We have seen that a fairly coarse abnormal grain is not impossible, but it is the exception. On the other hand, it has been shown that, other things being equal, the fine-grained austenite transformed more rapidly, appeared more abnormal as cooled, and hardened less deeply than the coarse. It is possible now to inquire whether austenite grain size may not (Continued on page 62)

Aluminum Steels Are Normal. If pack carburized, a thin surface layer is abnormal, and develops a shower of small particles, thought to be alumina. 1200 and 3500 diameters



OPERATING EXPERIENCE BUILT INTO

28 - FOOT

NORMALIZER

By J. M. Watson
Metallurgical Engineer
Hupp Motor Car Corp.
Detroit, Mich.

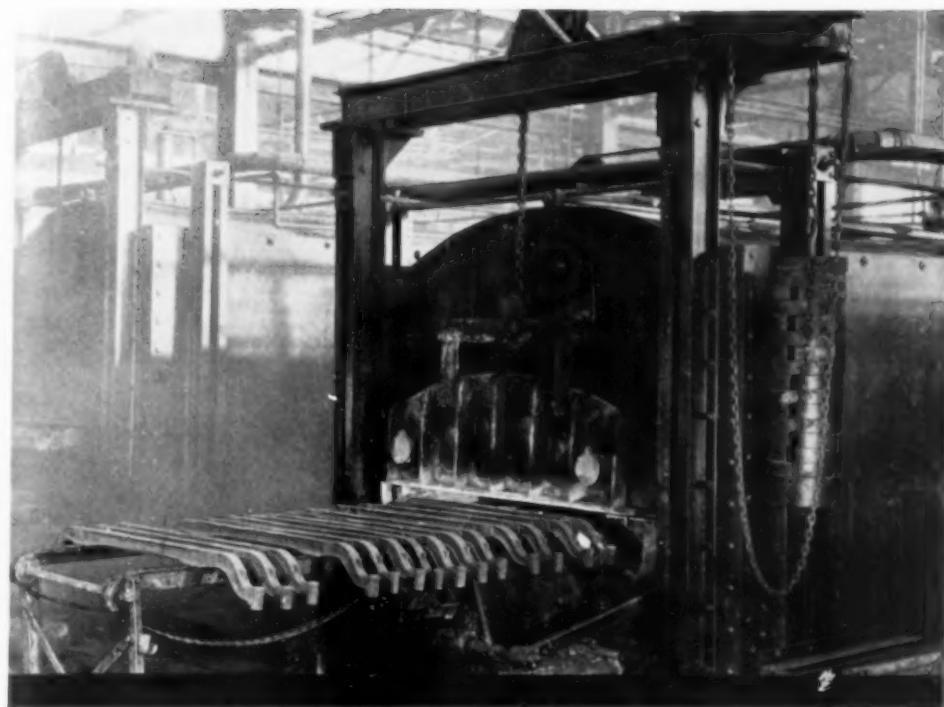
DURING the past 15 years a fundamental change has taken place in the design of heat treatment furnaces wherein the batch-type and its cousin the car-type furnace have given way to the continuous type. It has been the writer's fortune (good or bad) to have been in charge of the operation of a sizable heat treatment plant during this transition, and it is my present purpose to indicate some of the troubles we surmounted with an early installation of continuous furnaces, and to show how this experience has been utilized in later additions to our equipment.

Jackson Division of Hupp Motor Car Corp. finishes front axles and knuckle work, together with a wide variety of miscellaneous forgings and castings that experience has shown we can handle economically. Before 1922, all parts that required heat treatment were purchased in that condition, but at that time it was decided that

we should heat treat steering knuckles and arms. For this purpose two small batch-type furnaces were installed in temporary quarters and gave gratifying results.

To handle more and more of this class of material, a lofty, well-ventilated, glass-walled building some 75x125 ft. in area was erected, and a contract placed for one continuous normalizing furnace and two tandem pairs of quenching and tempering furnaces (all oil fired) together with quenching tanks, conveyors, and cooling system. One of these tandem furnace units was for front axles, the other for small parts. The latter was duplicated in 1926 to care for increased production.

This new department was ready for operation toward the end of 1923, but for several months was subject to various "growing pains." The conveying mechanisms were weak in a number of connections and details (and to correct these as trouble appeared meant several shutdowns and much hot emergency work). On the other hand, the furnace proper—brick-work, binding, and doors—occurred no trouble whatever, then or since. The buckstays and plates are as straight now as the day they were erected; no major repairs to brickwork have been necessary in 10 years. (One furnace



Axles, Chloride Treated, Passed Through by Walking Beam

Combined Action of Chloride Solution and Heat Loosens Scale so it Shells Cleanly From Steel During Handling

and a number of changes made. In the heating furnaces, which ran too hot in the center and too cold at the ends, a number of openings in the false arch were closed, the baffles around the combustion chambers relocated, the door jambs enlarged to barely clear the moving parts, and an arch of insulating brick built at the discharge end to deflect the exit

gases down toward the hearth.

Similar changes were also made on the low temperature drawing furnaces, but this did not correct the troubles. Since the operating temperature is lower, the arch could not get hot enough to transfer much heat by convection. Furthermore, the furnaces for handling small parts had a pan conveyor hearth, which weighed about as much as the work it carried, and which, being a continuous plate, could not be penetrated by the gas currents and was always colder than it should have been. Consequently, a new firebox was installed *below* the hearth, with generous volume of checkerwork to discharge the hot gases on the under side of the loaded conveyer while it was passing the center of the furnace.

These changes (which, of course, were individual for each furnace and made only after close observation of operations) have done everything that we have expected. Fuel oil consumption has been cut roughly in half, furnace outputs have doubled the rated 1000 lb. per hr., and the temperature gradation inside the furnace is correct and the soaking zone uniform no matter what quenching or drawing heat is specified.

Here is probably the place for mentioning our system of recording and controlling pyrom-

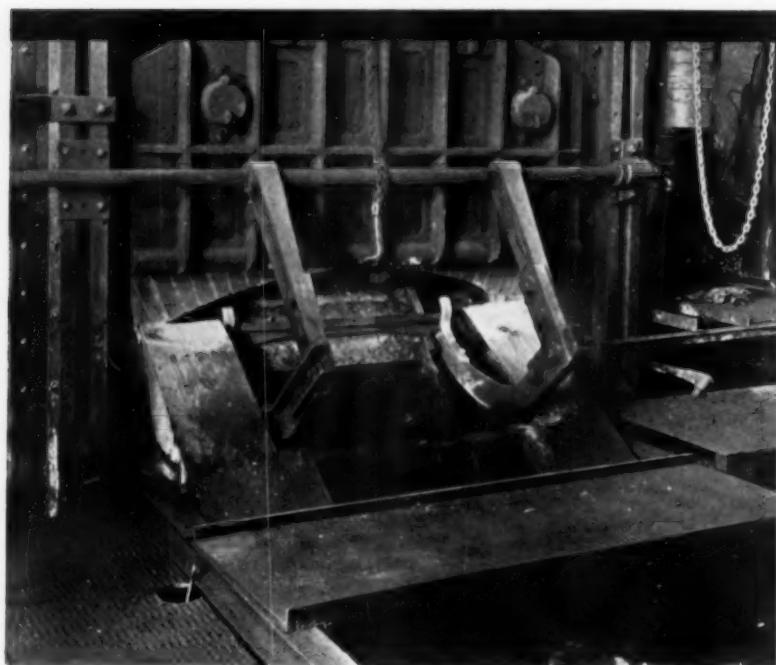
has been pointed up once with high temperature cement. Carborundum bricks lining the combustion chamber must also be renewed every other year or so.)

These furnaces were also among the first to have the Ryan-Scully dual automatic control of both oil and air at the burners. Once we found out how to adjust the various burners, each to each, and how to distribute the products of combustion inside the furnace, this device has worked very satisfactorily and will hold the heat to $\pm 5^{\circ}$ F. of the desired point.

As built, all the furnaces were over-fired, three oil burners on a side, the hot products of combustion going down through openings in a false arch, bathing the work below, and passing out the doors at either end. Heat was transferred to steel by radiation from the hot arch above and by convection from the hot gases. It was intended that the furnaces (all approximately 5x18 ft. in hearth area) would bring the work to temperature by the time the steel reached the middle, where the control pyrometer was placed, and the remainder of the tunnel would be a uniform soaking zone. However, the location of the burners and of the openings in the arch was such that it was impossible to secure these results at the outset.

Consequently the furnaces were shut down

Anti-Splash Quenching Arms



Door Opened and Steel Plate Removed to Show Axle Starting Down the Skids Into Tank of Quenching Oil

eters. The pyrometer-well in each furnace contains two thermocouples. One is connected with the controlling mechanism and an indicator nearby where the operator can see it. Another is wired to its own single-point recording potentiometer in the office, where it makes a permanent record, and operates "over and under" lights at the furnace. Each set checks the other. While it might seem that this is an extravagance, we believe it has resulted in an over-all economy, since it has avoided much expert labor for constant checking. When any pair shows divergent results, repairs are promptly made, or if beyond our means or knowledge, a spare is installed and the out-of-order set is shipped to the maker.

All of the furnaces except the pair handling axles had a conveyor hearth consisting of a series of flat-topped slabs, so designed that balls on the trailing corners fitted into sockets on the leading corners of the next. As shown in the view on the opposite page these slabs fitted into a continuous chain; their under side also had grooves to fit the skid rails, and deep recesses to catch a finger on the pusher mechanism.

Such a design required some rather large variations in section throughout the casting, a variation which should be avoided in parts

which are successively heated and cooled. Heat checks usually start here and work their way into the casting, eventually cracking and warping it beyond use or repair. Heavy slabs of metal also cut down the efficiency of the furnace; too much heat is absorbed and carried out of the tunnel by the conveyor. Finally, a solid bottom of metal prevents circulation of hot gas through the charge, which is essential for low temperature operation.

When our present supply of spare conveyor castings runs low we intend to install a new design in the old furnaces, consisting of a pair of endless chains to the links of which will be bolted thinner tray castings of uniform wall thickness, perforated for circulation of gases and corrugated for stiffness. These ideas have already been tested in a new normalizing furnace which will be described later.

In general, heat-resistant alloy castings are of much better quality now than 10 years ago. It is to be hoped that the next improvement will be a material which will resist both heat and the action of certain chemicals originating in the pickling operation. Such materials would enable us to clean all parts much cheaper than we can at present.

Scale (originating in forging, normalizing, heating for quenching and for tempering) is a great nuisance. It must, of course, be entirely removed before sending the parts to the machine shop. After long experience with tumbling barrels, which batter up the pieces and fail to remove all the oxide, we have turned to sand blasting or rather "sand-shot" blasting, for a mixture of sand and shot economizes on air and cleans quickly. This dusty operation is performed in a detached building, and we prefer it to pickling with sulphuric acid.

We are using a much simpler method of cleaning scale from front axles. Just before loading them into the hardening furnace they are immersed (covered with oxide from forging and normalizing) in a tank of chloride solution for a few minutes. This has little immediate

effect on the oxide, but after the piece comes out of the hardening and drawing furnace, the scale shells off cleanly and completely by merely dropping the axle on the floor.

Such a practice would be impossible if the axle hardening furnace contained the ordinary heat-resistant alloys. It, however, is of a walking-beam type; axles (spaced some 6 in. apart) rest on brick walls. The walking beams periodically emerge through narrow slots in the floor and move the beams ahead a few inches, and immediately retire to the cooler channels below. Consequently, common carbon steel can be used for these furnace parts.

Some interesting handling devices and furnace auxiliaries have been installed since heat treating operations started in the Jackson plant. The axle quenching tank and conveyor, for instance, was designed on the assumption that an axle, fed sidewise into the heating furnace, would remain square with the centerline at all times throughout its travel. As a matter of fact, one end may go along a little too fast, and land on the inclined skid leading to the quench tank at a time when the other end is still on the flat. Such an axle would drop into the oil end-on rather than sideways, and get tangled up in the elevating mechanism.

To avoid such trouble, a double-armed device shown in the halftone on the opposite page was provided. These arms are keyed to a shaft extending across the end of the furnace, and at the outboard end a counterweighted lever is attached. This also is linked to a pneumatic dash pot. The function of the counterweight is to swing the two curved arms inward toward the furnace in such a position that the ends or

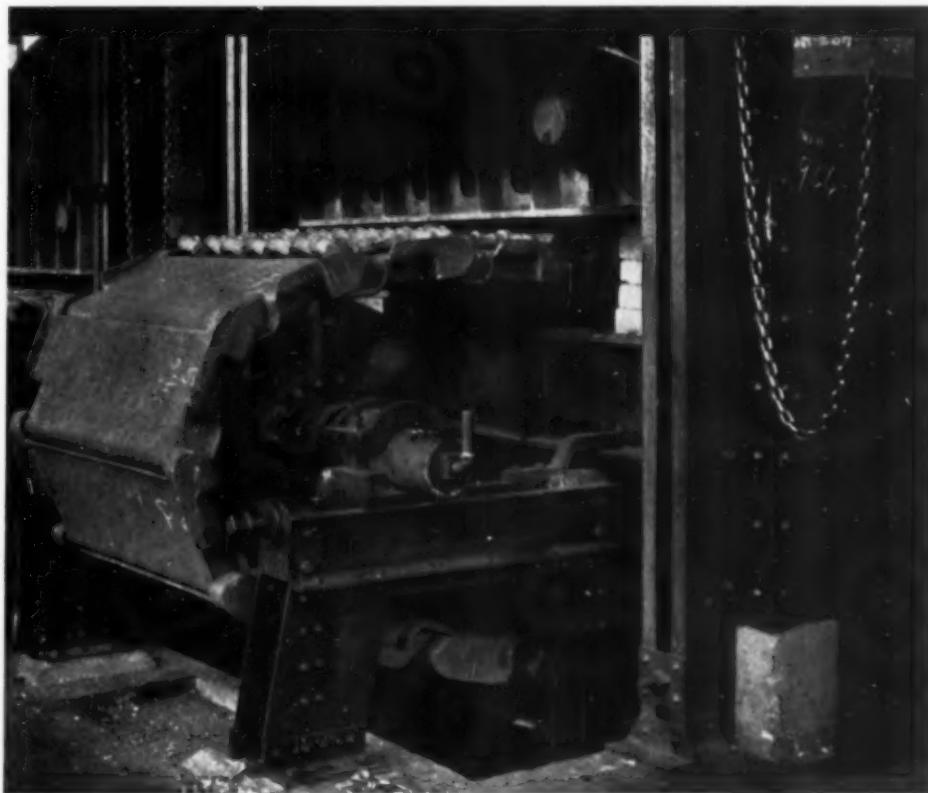
"hands" reach into the hot zone and assume a position just below the top of the incline, where a hot axle headed for the oil must strike them. If the axle is askew in the furnace so only one end strikes one hand, the counterweight is heavy enough to hold it there until the other end of the axle starts sliding down and strikes the other hand, whereupon the total weight is sufficient to move the arms back quickly. Just before the hot metal strikes the oil the dash pot comes into play, slowing down the speed and preventing a great splash.

Much Equipment in Duplicate

Much of the auxiliary equipment is installed in duplicate. We have two fans, each directly connected to its own motor, and each capable of furnishing all the air necessary when each oil burner is open. If one fails to operate, we close a gate in the air main, open another, start the second motor, and make repairs at leisure. Similarly, we have duplicate fuel oil pumps, oil circulating pumps, oil cooling tanks, and water circulating pumps.

Circulating and cooling system for the quenching oil was figured to have 50% excess

Slab Conveyors on Small-Parts Furnaces



Fuel Efficiency Could be Increased by Perforating Slabs so Gas Could Circulate Through Charge

capacity when installed, which was a wise provision. Each oil cooling tank is partitioned by vertical plates, the oil goes under the bottom of the first, over the top of the second, under the third, and so on. In each vertical compartment is a nest of $1\frac{1}{2}$ -in. pipes carrying cooling water. The water carries calcium bicarbonate in solution, and the moderate heat of the oil breaks down this compound and has crusted the interior of the pipes with lime scale, which is a good insulator. This accumulates at the fittings and further cuts down the water flow. Sludge from the circulating oil also accumulates on the outside of the pipes, which helps insulate the cold water inside from the hot oil outside.

New Cooling System Planned

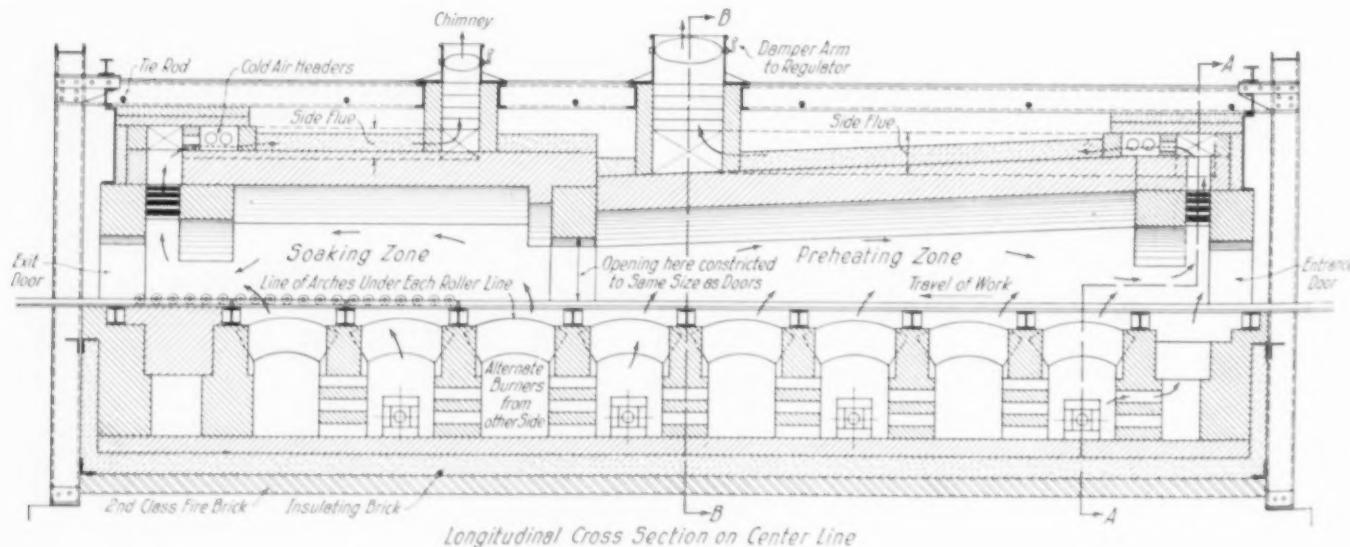
Plans have been drawn to replace this system with a series of oil pipes of generous diameter, to be laid near the bottom of an existing concrete-lined spray pond. With filtered oil inside the pipes and a great excess of cold water outside, the growth of insulating deposits can be avoided, or at least held in check.

Perhaps these early troubles have been experienced in other places, and surmounted as successfully as they have been at Jackson. The account of them will give the reader an idea of the background used in designing the 28-ft. normalizing furnace (in cooperation with Ryan, Scully and Co.) built in 1929. It operated successfully the first day the fires were lighted, and has caused no trouble whatever nor required any repairs since that time.

Drawings printed below show that it is underfired with eight oil burners, four on a side. Each has a generous combustion chamber, consisting of a passageway 18 in. wide and 19 in. high extending across the furnace. Walls separating the chambers are perforated by numerous openings, so they, with the series of arches covering them, form a checkerwork for diffusing the flow of hot gases and absorbing a store of heat.

Work is carried through on perforated trays, pushed along on four parallel lines of rollers. These rollers and supporting channels rest on seven crossbeams, located midway between burner openings. Rollers are protected from direct blast of hot gases by a series of firebrick arches, each series with their spandrels comprising a thin wall end to end of the furnace holding the rollers in true line. Half section A-A, printed on the opposite page, shows how the hot combustion gases work up between roller-lines and at sides of the hearth.

Main roof is arched, in a distinctive manner. From the charging door the roof slopes downward to a point somewhat past midlength, where is located a constriction in the form of a low arched rib or "suspended arch." The soaking zone has a somewhat higher roof in the form of a horizontal barrel. Hot combustion gases, well distributed by checkerwork, work up through the load of steel and are drawn part toward either end through vents or ports built through the roof just inside the entrance door and the exit door. These gases then pass through flues built in the tops of the furnace

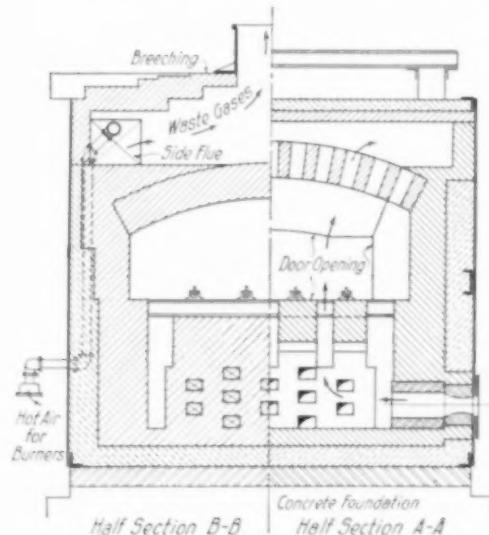


sidewalls to a double breeching at the center of the furnace, and thence out two short stacks provided with butterfly dampers. These dampers are connected by proper links and levers to the temperature control mechanism, and open or close gradually as the fuel supply increases or decreases, thus maintaining a constant pressure of a few ounces above atmosphere. This means that there is a small blow-off at all times around the doors, and when they are opened momentarily to charge and discharge a tray, little or no cold air can enter. Much more fuel is necessary for the heating half of the furnace than in the soaking half, so the passageways, breeching, and stacks are properly proportioned. Closer control of relative volume of gases in the two ends is attained by adjusting the mutual relationship of stack valves. Each half of the furnace has its own pyrometer and automatic temperature control.

Cold air from the main fan is carried through steel pipe headers laid inside the waste gas flues. Down pipes to each burner take off at appropriate places and are embedded in the walls. By this means preheated air at about 500° F. is delivered to each burner.

Insulation Is Very Efficient

All brick below the hearth line is high alumina firebrick laid in high temperature cement. Sidewalls are 13½ in. thick and are separated from bindings with 7 in. of insulating brick. The result is that the bare hand can be held without discomfort on the metal sheathing



of the furnace at heat. Another indication of its excellence is that in the morning, 13 hr. after shutting off oil, the furnace is still at 1100° F., a bright red heat.

The furnace foundation is in a pit, enough below floor level that the roller hearth and charging platform are waist high. In this manner the loading labor (and this is the only labor required) is minimized. One man can put 4000 lb. per hr. through the furnace. Light forgings are placed in the trays level full; axles are then loaded on top. The doors, at maximum opening, clear the tops of the trays about 10 in. A full furnace contains about 5 tons of forgings; 2 to 2½ hr. is required for transit.

Trays themselves were made by Michigan Steel Casting Co. and are formed like open-top rectangular boxes, with one long side missing. The shape is clearly shown on the next page. (Since they butt one against the other and are pushed through the furnace, the rear side of the leading box forms the front side of the one following.)

Dimensions are about 48 in. by 12 in. by 6 in. high. Uniform thickness is ½ in.; side, ends, and bottom are slotted freely for gas circulation. Low flanges on the bottom engage the rollers and keep everything on the track. Bottom and side are corrugated for stiffness. Every effort has been made to avoid change in section (for the reason discussed above). After three years' service these "Misco" alloy parts look as good as new, except where some tray ends are slightly peened on top edges where front axles have been dropped on them. In fact, there have been no failures of any nature in any of the parts of this furnace, either of brick or alloy.

Trays returned from the unloading device are placed on an extension of the roller bed and filled with cold metal to be normalized. At regular time intervals, signalled by time clock, the attendant opens the valve of an oilgear pusher. That is all he has to do. All necessary furnace motions are interlocked with this charging ram, such as opening doors, pushing a cold trayload in, and shoving the furnace contents ahead so that a hot completed load is discharged, closing doors, dumping the loaded tray, and elevating the hot empty tray to a sloping roller conveyor to bring it back to the start.

Automatic Device for Discharging and Returning Trays

Cylinder, Interlocked With Pusher at Other End, Raises Hooks Which Have Entered Lugs on Rear Corners of Advancing Trays. Trays are tilted, dumped, and landed on roller conveyor above. Hooks then return to starting position and await next pan.



Automatic unloading devices shown above are especially valuable. Each tray has projecting ears on the trailing lower corners, and these slip over hooks hanging from an overhead yoke as the tray reaches the end of a slightly sloping discharge table; thereupon the yoke starts up (raised by a steel cable leading by appropriate sheaves to a hoisting cylinder) and the tray tips forward, spilling its contents out the open side on an elevating pan conveyor which discharges into appropriate skid boxes. The yoke has rollers at its ends, and these engage curved guides so the yoke (and the box hanging below it) goes up and over the starting end of a roller conveyor. Reverse motion on the hoisting cylinder frees the hooks from the tray, and returns the yoke to position ready for the next cycle. The tray slides by itself around to the other door. As before mentioned, all these motions are set in train by the oil-gear pusher, and no attendance is required at the discharge end except by the driver of a lift truck, who periodically moves a loaded box away and puts an empty one in place.

It will thus be seen that in this new normalizing furnace we have incorporated many of the fundamentals of good design, often overlooked in early installations, such as:

- (a) Reduce number of moving parts inside furnace to a minimum,
- (b) Avoid change in section on all heat-resistant castings,
- (c) Ventilate carriers or trays freely, for gas circulation,
- (d) Avoid mass in carriers, which take heat out of furnace to no good purpose,
- (e) All parts (moving or stationary) should have ample strength and generous bearings,
- (f) All portions of the mechanism should be accessible for inspection and repair,
- (g) Interlock all devices into one automatic unit for efficient operation,
- (h) Control path and volume of hot gases inside furnace,
- (i) Maintain slight over-pressure,
- (j) Utilize waste gases to preheat air for combustion,
- (k) Insulate furnace efficiently.

THERMOSTATIC METAL — OR BIMETAL

NATURE &

UTILITY

By H. Scott
Research Laboratories
Westinghouse Electric & Mfg. Co.
East Pittsburgh, Pa.

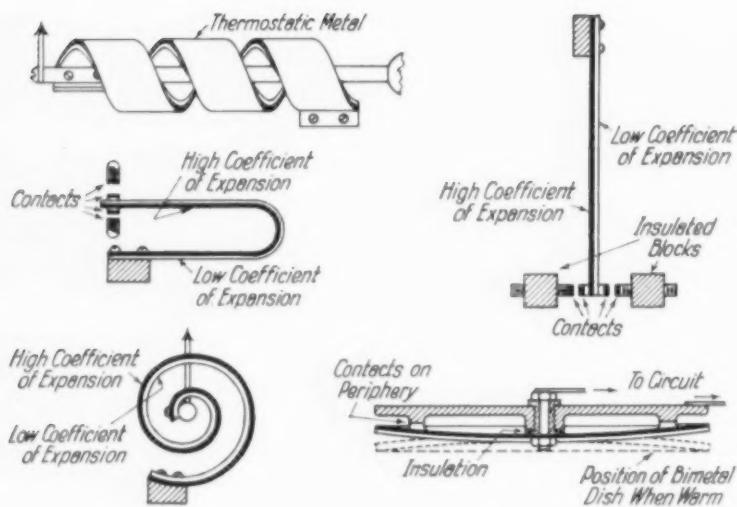
THERMOSTATIC metal, bimetal for short, forms the actuating element in many devices that unostentatiously control temperature or protect electrical machines for us. Among many other things it regulates house temperatures, prevents overcharging of automobile batteries, protects lighting circuits, and snaps the power off sad irons before they reach a burning temperature. Only a few of the interesting applications can be shown in accompanying illustrations.

Although the commercial application of thermostatic metal is quite recent, the material itself is old. U. S. patent 24,896 was issued to Wilson in 1858 on a combination of brass and steel, and the Breguet thermoscope (employing a combination of gold, silver, and platinum) probably antedates even this. Bimetal was not used extensively, however, until the discovery of invar — a relatively cheap and efficient alloy with low expansion.

Since the literature on bimetals is meager, and confined largely to patent specifications, a brief account of the matter in *METAL PROGRESS* should be of value. H. M. Biebel of the Westinghouse patent department has kindly placed his special information at my disposal.

Bimetal, as the name implies, is composite sheet metal, half the thickness of which is made of a high expansivity metal and the other half of a low expansivity metal. ("Expansivity" will be used in place of the cumbersome term "temperature coefficient of expansion.") The component metals are first brazed or welded together when in the form of two plates much thicker than the finished sheet. The method of forming the joint is important, and a uniformly good and strong weld is necessary to resist the high shearing stresses which exist on that plane when the metal is warmed or cooled. The composite block is then rolled into strip. Pieces are then cut and used, as cold rolled, without eliminating the hardness acquired from cold rolling.

The technical value of bimetal resides in its ability to bend with change in temperature. The bending may be converted into more useful forms of motion by devices such as those sketched in the first drawing. These, with one exception, are very unsatisfactory for making



Typical Forms of Bimetal Thermostat Elements for Operating Indicators and Controlling Currents

and breaking electric circuits. Because of the slow motion, proportional to the rate of temperature change, arcing occurs between the contact points; even if controlled by an electric condenser, only very small currents can be directly made and broken with reliability.

The objections to the conventional type of bimetal-operated thermostat were overcome by Spencer with his disk-type thermostat sketched at the bottom right of the first group. This thermostat gave a strong impetus to the development of new bimetals, and it was described in 1921 by V. G.

Vaughan, manager of appliance engineering of the Westinghouse Co. (to whom I am indebted for much of my data on thermostats), in *Electric Journal*. It is a cupped disk or flat dish having contacts mounted near the periphery. It bends on heating in a direction which tends to diminish the depth of the cup. When a certain critical temperature for which it is adjusted is reached, it snaps over into a reversed cup with the speed of a rifle bullet.

Such a rapid opening and closing of the circuit practically eliminates arcing as a problem, and by virtue of large silver contacts and

high contact pressures large currents may be handled with ease. It is very compact; a unit 1 in. in diameter and $\frac{1}{2}$ in. thick will control 6 amp. at 110 volts, a.c., while operating at 300 C. The physical characteristics of the bimetal are not precisely the same at opening, closing, and fixed operating temperature, but this matter has been overcome by several expedients and refinements in design.

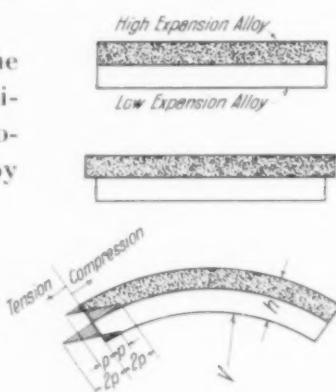
Before discussing the metallurgical requirements of bimetals, it is desirable to survey briefly the mechanics of the action. Timoshenko has published the only scientific analysis in 1925 in *Journal of the Optical Society of America* and *Review of Scientific Instruments*. He found that the bending of bimetal with temperature follows simple laws, and many of his analytical deductions have been confirmed by experiment. Some of these analytically derived relations are given in following paragraphs.

The basic principle of bimetal flexing is

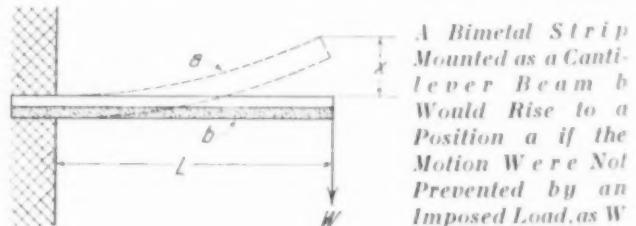
illustrated by the diagrams at the left. If two metals of widely different expansivity are cut to the same length and laid one upon the other, and then heated, there will be noted a considerable difference in length, but no change in curvature. This is shown at (b). If, however, the strips are rigidly joined

while flat at room temperature, they will bend as indicated by (c) when heated to a higher temperature.

Curvature change, V , of a narrow bimetal strip of thickness h on heating T degrees, when the difference in mean expansivity of the components over the temperature range chosen is A , is given by the equation $V = 3AT : 2h$. It is evident that the change in curvature, other things being the same, is inversely proportional to the thickness of the bimetal. The thinner



Action of Differential Expansion of the Components in Bending Bimetal, and the Magnitude of the Internal Stresses Produced



the strip, the more it should move when heated.

Bimetal is often used as a cantilever; that is, a strip is rigidly held at one end and does useful work such as tripping a latch at the other end. This is the simplest form of mounting and one well adapted to illustration. A narrow bimetal strip so mounted is shown in the lower sketch. Deflection X at the free end may be calculated from the curvature change on heating and the active length L by means of the relation $X = \frac{1}{2}L^2V$ when the change in curvature is very small.

Combining with the previous equation, we have $X = 3L^2AT \div 4h$.

Thus we see that a given bimetal strip, heated over a specified temperature range, will deflect an amount directly proportional to the square of the length and inversely proportional to the thickness. Hence for maximum sensitivity it should be as long and thin as possible.

A bimetal is often required to exert considerable pressure at the free end in order to actuate a mechanism. This requires that a certain amount of thermal deflection be annulled. The efficiency of a bimetal for this type of service may therefore be measured by the load W at the free end required to annul unit thermal deflection. This property is often called "activity."

From elementary mechanics it may be stated that the deflection of a cantilever loaded at the free end is inversely proportional to the elastic modulus of the beam. Hence the activity of a bimetal is proportional both to the difference in expansivity of its components and to the effective elastic modulus of the combination. One may therefore improve the activity by either increasing the difference in expansivity between its components or their mean modulus of elasticity. Little can be accomplished by the latter alternative, however, because the elastic modulus of metals responds only slightly to alloying.

Choice of Components

From the foregoing one might choose zinc as the high expansion component and tungsten as the low expansion member, because of the great difference in expansivity between them. It is evident at once, however, that this com-



Tiny Watchman Thermostat

Contacts Are Carried at Edge of Shallow Bimetal Cup, Which Suddenly Turns Inside Out at a Certain Temperature

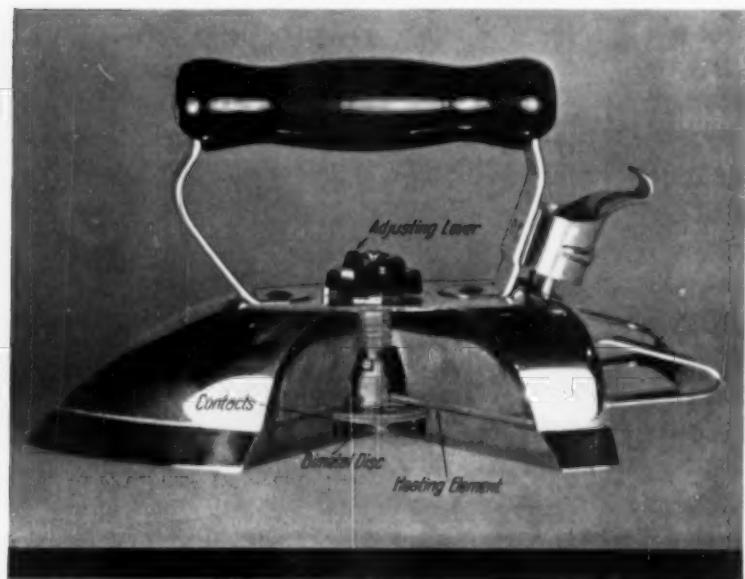
bination is not a practicable one, because of the softness of zinc, its low melting point, and the difficulty of joining it to tungsten. In fact, no combination of pure metals will meet modern demands. The high expansion metals are too soft and the low expansion metals too hard or expensive to meet practical requirements.

As stated at the outset, commercial exploitation of bimetal started after a suitable low expansion alloy known as invar became available. Invar, a ferro-alloy containing about 36% nickel, has an expansivity of zero or close thereto at room temperature. There are many high expansion alloys that may be combined with invar to form serviceable bimetals. Guillaume (the discoverer of invar) used an austenitic nickel-chromium steel in the first bimetal employing invar (1899 U.S. patent No. 626,609).

Three patents were issued in 1917 on combinations of brass and invar which have exceptionally high sensitivity at room temperature. Brass-invar is widely used, but is not satisfactory where temperatures much above 100° C. are encountered. Peculiarly enough, when rolling down the composite block, the thickness of the brass is reduced proportionately with that of invar, despite the considerable discrepancy in hardness between the two metals.

Bimetals having much better stability and ability to survive overheating are now available.

Bimetal Element, Sunk in Base Under Heating Element, Quickly Responds to Fluctuations in Temperature of Working Surface. This may be adjusted by top lever which increases or decreases curvature of bimetal disk



Cut-Away View of Automatic Iron

In them brass is replaced with one of the new austenitic corrosion-resistant steels. The improved characteristics were obtained, however, only by sacrificing the sensitivity. If an austenitic nickel-manganese steel is used as the high expansion component, the stability of a ferrous alloy may be secured as well as the high sensitivity of brass-invar (U.S. patent 1,671,490). Thus we now have a variety of bimetals with high sensitivity up to 100 or 150° C. and the ability to withstand overheating. Control of atmospheric temperatures has many obvious applications. Temperatures approaching the boiling point of water are to be accurately controlled in the dairy industry, and in all manner of sterilizers. Devices to keep water at body temperature avoid unnecessary pain when flushing out tender dental cavities.

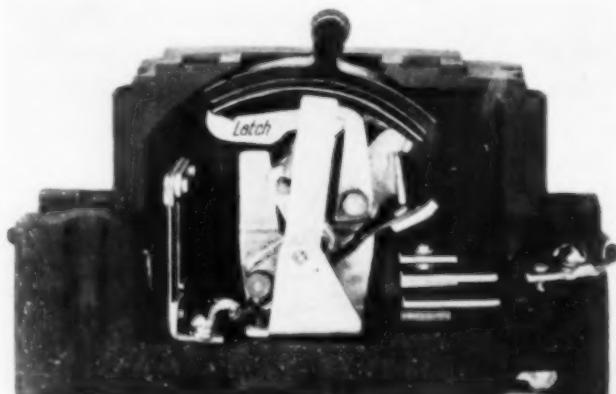
Vaughan, in the reference already cited, has pointed out the need for bimetals having high sensitivity at temperatures around 300° C. combined with stability — that is, reversible deflection properties. These, for instance, are very useful on waffle irons and kitchen ovens (to mention only a few of the more common applications not illustrated on pages 32 and 33). To meet that demand a low expansion nickel steel of higher nickel content than invar was required. Marshall has patented 42% nickel

steel for this purpose. Its expansivity at room temperature is considerably higher than invar, but whereas invar expands rapidly at temperatures above 150° C., the 42% alloy has a range of low expansivity extending from 150 to 300° C. approximately. Consequently, bimetals employing the higher nickel content steel have a high sensitivity at 300° C., in fact, are considerably more sensitive than they are at room temperature. They are broadly designated as "high temperature bimetals" in order to distinguish them from those in which invar is used and which lose their sensitivity at temperatures above 150° C.

One of the first components used with 42% nickel steel (and a very successful one as well) is monel metal. Monel is closer to the low expansion nickel steels in physical properties, other than expansion, than any other useful component. This is an ideal condition, because such a bimetal will fabricate much the same as a mono-metal. The chief disadvantage of monel bimetal is its low sensitivity, which is about two-thirds that of brass-invar.

Greater sensitivity has been attained in high temperature bimetal by the use of austenitic steels in place of monel. These alloys, however, are harder than the low expansion alloy. In fact, no known combination of equally hard

Cut-Away to Show Bimetal Strips at Left Which Hold Latch Unless Heated by Dangerous Currents



Fliron to Protect House Circuits

components has an activity as great as that of brass-invar, but discovery of such a bimetal may reasonably be expected, since constant experimental work is under way.

Bimetal is of interest to the investigator who studies high temperature creep in metals, a phenomenon now receiving so much attention.

At high temperatures high stresses exist in bimetals. If creep (that is, plastic or unrecoverable deformation) occurs, the bimetal is permanently deformed and accordingly its calibration or operating temperature is changed. Precautions must evidently be taken in order to avoid this. When the essential precautions are taken, phenomenal performance is obtained. Vaughan mentions a thermostat element which operated 325,000 times at 300° C. without failure of the metal. To produce that number of operations it was necessary to heat and cool as rapidly as possible for a period of 4½ years. At least 200 years would be required to give an equal number of heating cycles under normal operation in a sad iron.

Stresses in Bimetals

The significance of the foregoing observations can be better appreciated if the magnitude of the operating stresses is calculated. Timoshenko has shown that the stress distribution at an elevated temperature in a bimetal free from stress at room temperature is that shown in the center sketch on page 30, when the components have the same elastic modulus. The stress at the joint between the components is twice as great and of opposite sign from that at the outer surface of the same component. The value of

Marking Hard Rubber With Hot Type



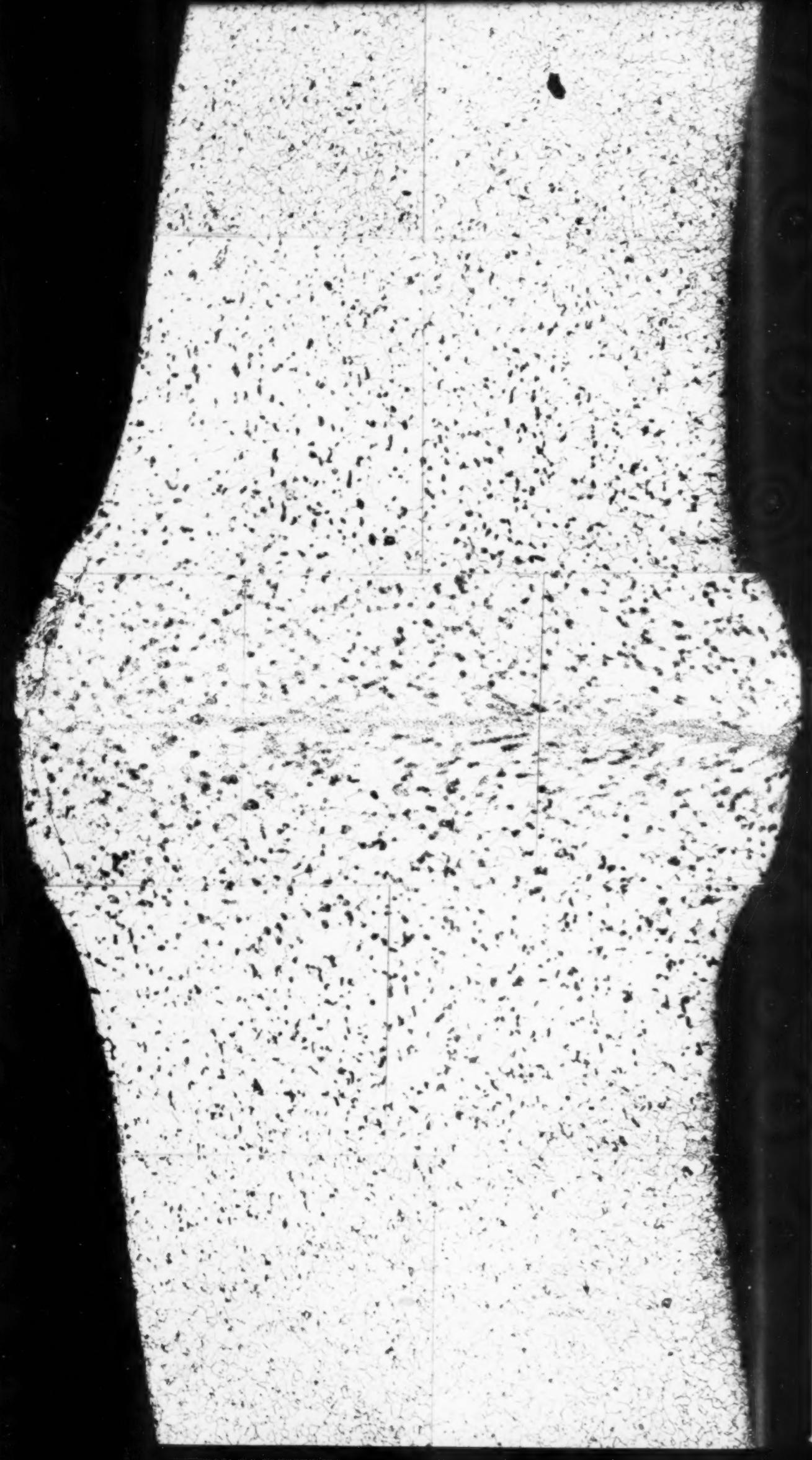
Precise Temperature Control Is Secured by Built-In Watchman Disk Thermostat Within Shield at Left

the maximum stress p is given in terms of the modulus E by the equation $p = \frac{1}{2}EAT$ (notation as above). In the case of a bimetal composed of monel and 42% nickel steel, the maximum stress at 300° C., assuming no stress at room temperature, is about 35,000 lb. per sq.in. Thus a strong, uniform joint is necessary.

Bimetals also offer an attractive means for the study of residual stresses in metals. By heating a flat strip while constrained flat, residual stresses can be easily induced. They will have the same distribution when the strip is released at room temperature as the stresses produced by heating free, except for signs which will be reversed. If the creep characteristics of the components are the same, the magnitude of the residual stresses may be calculated from the curvature of the strip measured after release at room temperature by means of the equations already given.

Evidently thermostatic metal has many stimulating possibilities from the viewpoint of the physical metallurgist as well as of the manufacturer of electrical devices.

Joint in Tube Made of 0.06-In. Strip by Edge-Surface Weld



E D I T O R I A L



ANOTHER annual convention and exhibition has come and gone to confound the doleful predictions of the pessimists! A.S.S.T. technical sessions held down to three papers on closely related subjects kept within the fatigue limit of the audience and consequently drew forth a gratifying amount of discussion from the floor. A brilliant Campbell Memorial Lecture was presented. Best of all, a generous attendance of the right quality was counted at all meetings and at the Show.

The National Metal Congress, though not as large as some non-exhibitors admitted it should have been, was certainly the best looking ever held. Of course, each year there have been some booths arranged and decorated with rare good taste, but in Buffalo in 1932 this seemed to be the rule rather than the outstanding exception.

In part this was due to the large proportion of firms that exhibited the stainless alloys or brightly finished die castings or alloy parts. A larger part comes from the growing importance of eye-appeal in all selling effort. Even though the things may be as prosaic as bolts and nuts, prospective customers can be drawn to a closer examination by a good display among inviting surroundings.

* * *

THAT MATTER OF EYE-APPEAL — color harmony, design, style — has been actively commercialized by purveyors to woman-kind since the beginning. It has only recently been rediscovered by manufacturers of more work-a-day utensils. Take for instance washing machines — why should they be good looking? Simply because they sell better than a homely competitor. They sell better not only because they

attract the eye of the purchasers, but he and she are more easily convinced when the manufacturer has well taken care of externals they can see, that he has also taken care of many essential internal mechanical details they can't see.

Leading art schools and municipal art museums are actively promoting the idea that quality in finished goods not only includes fine material, and workmanship, but also fine design. Fine design includes artistry of shape and color, and an appearance of utility. No argument is needed to establish the desirability of good looks in all things. Some question exists as to how much money it is worth. While men have seldom reached the advanced stage of their wives (willing to throw away a workable machine or tool merely because it is out of style), they also are strongly attracted by workable and workmanlike appearance — that is, fine design. An ugly automobile can't be sold, even to a bachelor.

Much might be said in support of the proposition that a properly designed work, be it tool, machine, or structure, will performe be good to look at. Whenever each of a bundle of units is properly placed to assume the working loads, and these loads are uniformly distributed in accordance with the strength of the parts, then an aesthetic appearance is inevitable. Stated in another way, an ugly machine or structure is not properly engineered. It is repellent because it is ugly, and also because we instinctively know there is something wrong with it.

* * *

ALL THIS HAS SOMETHING to do with current experimentation with steel houses, some of which are not good to look at.

Would not their promotors do well to re-

member the development of automobile bodies? This is so recent that we do not need to go to books for the history. We can still remember the early Cadillacs with a body patterned after a surrey (a popular horse-drawn vehicle of the gay 90's, as the younger generation probably does not know). It quickly became apparent that the chassis of an engine-driven passenger vehicle had entirely different requirements than those for a horse-drawn carriage, and changes in the design were as quickly made and as quickly accepted by the purchaser as correct.

The present developments toward streamlines took time—time for aircraft to show the engineering principles, time for good high speed roads and safe high speed cars to be built. The "tear-drop car" of 1933 or 1934 will therefore be right and proper from an engineering and dynamical standpoint. It can't help but be recognized as correct design, smart and good looking, by the purchasing public. But it would be as out of place, as bizarre, as ugly on a two-cylinder 1906 Reo as a surrey top would be on a 1932 Duesenberg.

* * *

THE POINT for our steel-house friends is that they should make haste a little more slowly. Spare us the outlandish shapes (in houses at least, if we must have them in filling stations). And when we say outlandish, we mean outlandish. A flat-topped adobe house is quite all right in arid Arizona, where it never rains, and where a couple of feet of earth will absorb the desert heat. A flat-topped steel house is quite all wrong in a temperate zone where it rains hard once a week. A peaked roof is not an architect's invention any more than a stone arch is. Both are forms which have been discovered independently by various peoples in remote ages and represent the best and simplest disposition of material for definite duties. Both are right and proper—and therefore good looking, harmonious, aesthetic.

* * *

AUTOMOBILES can be easily improved because they are so new. Cape Cod houses can hardly be improved because they are so old. Because we have had offices and office furniture for so short a time, a designer can do almost anything he likes with office furniture, and his "modern" lines will still be good. Because

we have been living in cottages for so many centuries he is helpless when it comes to the shaping of a house. The best he can do is to improve the details of construction.

This has some reference to the steel house. The builders will have enough to do to improve the internal details without hacking at the external forms (except, of course, of those kennels erected in highly artificial regions known as congested centers). Steel window frames and sash that are run up and down like automobile glass are ready for widespread adoption by home owners as soon as the cost is brought down out of the novelty zone. Steel fireproof floors, supported only at sidewalls, could carry steel room-partitions of the semi-permanent type (shifted about to conform to the needs of successive occupants) and thus greatly increase the useful life of the structure. Steel cabinets for linens should be as acceptable as steel cabinets for bath and toilet accessories have been found to be. Steel cupboards in kitchen and pantry can easily follow the steel-boxed refrigerator.

* * *

ALL OF THESE THINGS, which are clearly developments within the near future, will require many intelligent men. First they must be planned and the manufacturing technique developed. This will require special machinery and a thorough knowledge of the various sheet metals, welding methods and durable finishes. Design is a question which will never be settled, for it will require continued cooperation between stylist and production man. Promotion of the ideas will require many arguments with architects and builders, and some national advertising by metal and trade associations. Actual selling can best be done by someone who knows the advantages of the materials, finishes, and fabrication methods.

In the end, these developments indicate much employment for engineers and metallurgists. Happily it is not necessary for some ponderous corporation to get behind the idea. The various details of construction are each of them relatively small, and will undoubtedly be pioneered by small concerns with a forward viewpoint and energetic staff. The house-building industry is extraordinarily widespread and intricate, so now is none too soon to begin.

S T R U C T U R E O F W E L D E D T U B E S

M A D E O F

S T E E L S T R I P

By J. S. Adelson
Chief Metallurgist
Steel and Tubes, Inc.
Cleveland

METALLOGRAPHY of low carbon steels has been generally but erroneously considered quite simple. The total amount of iron carbide or cementite which can be formed in a steel containing 0.15% carbon is only 2.25% of the entire mass, and the maximum pearlite in the fully annealed state is 17.5%, on the assumption that all of the iron carbide is present as pearlite and none of it is soluble in the ferrite.

This last assumption is a notable error, as it has recently been demonstrated that ferrite holds about 0.04% carbon in solution at the critical temperature and about 0.01% at room temperature. Whereas this class of steels had originally been considered as practically unhardenable by heat treatment, investigation has proved that high physical properties can be so developed. For instance, bolts are now manufactured commercially from low carbon steels with tensile strengths which not so long ago would have been believed impossible.

It is true that a drastic quench is necessary

to produce these high physicals but this should not be taken as an indication that a milder quench, such as air cooling of a thin sheet after an anneal, has no effect on the physical properties. It is actually possible by proper heat treatment to increase tensile strength and hardness considerably with but comparatively slight decrease in elongation and contraction in area; on the other hand, the same increase in strength and hardness obtained through cold working is attained at the expense of ductility.

Quenching treatments, mild or drastic, modify all physical properties in these low carbon steels, but even slight modifications in the annealing processes will alter the properties, especially since the solubility of carbon in ferrite is influenced by traces of other elements as well as by cold work. These matters have been studied extensively by the manufacturers of sheets and strip, which consume a considerable tonnage of soft steel. Workability of sheets is of paramount importance, particularly to the automobile industry, and the present high grade of sheets would not be available without the application of selective annealing (variations in the temperature and rates of cooling).

The simplest annealing process is an air cool from just above the lower critical tempera-

ture, yet this does not yield a sheet or strip which meets present-day requirements. It is well known that a box anneal not only preserves the surface, but also yields a sheet of maximum softness, yet only within the last eight or ten years has normalizing above A_{c_1} been done to produce sheets combining both softness and toughness. In some instances two and even three types of anneal are given one sheet before a product can meet customers' specifications. Temperatures are varied and rates of cooling are changed to secure that combination of hardness and ductility for a sheet of highest workability.

Soft steels (containing 0.05 to 0.15% C) annealed by various treatments may look practically identical when examined under the microscope at a magnification of 100 diameters, except possibly for a difference in grain size. What pearlite there is may be lamellar or globular when examined at high power or may even be finely divided sorbite, but the total amount of carbide appears to be insufficient to have any marked effect on physical properties. As a matter of fact, there is only a slight difference in tensile strength of various samples, but there certainly is a marked difference in elongation.

On the other hand, such a steel, drastically quenched, shows the effects of rapid cooling. Compare *a* with *b* in this group of photo-

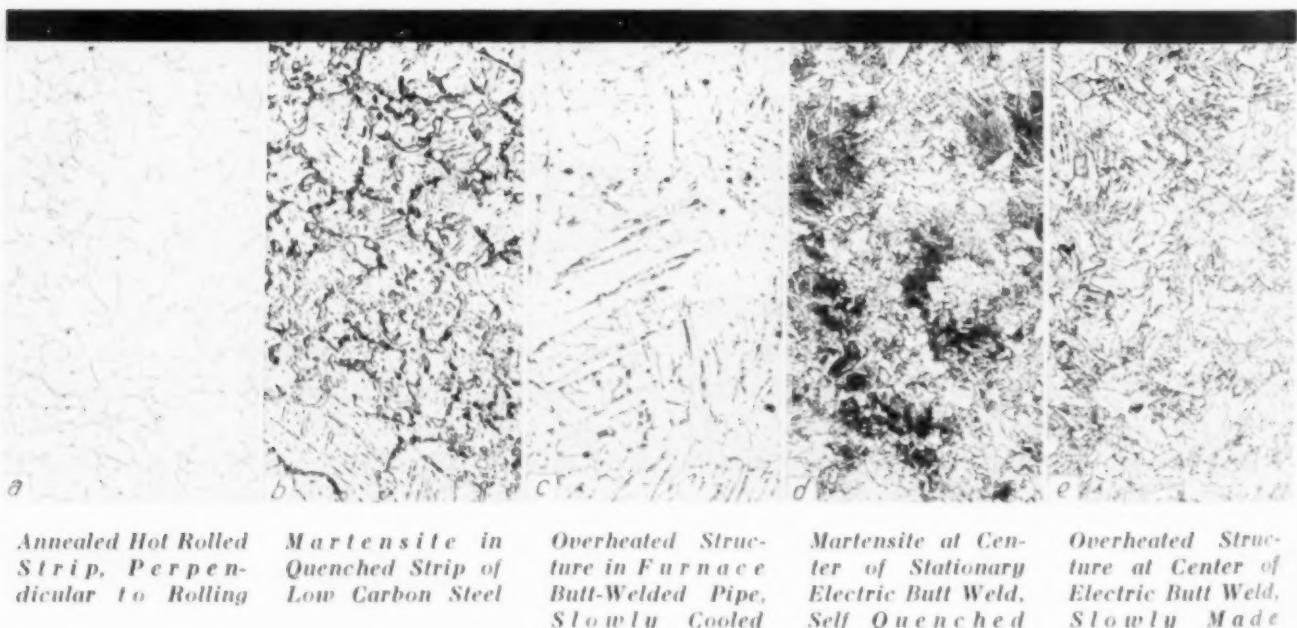
micrographs. The former is all ferrite with very little pearlite, whereas the latter is martensitic with the grains exhibiting the typical Widmanstätten structure.

Between these two extremes a multiplicity of structures can be produced in low carbon steels, many of which are to be found in welded joints. A brief description of the mechanics of the various welding methods, primarily with reference to their effect upon the microstructure, should serve as an interpretation of what is seen under the microscope.

In oxy-acetylene welding the abutting or contacting surfaces to be welded are heated by the flame until they are molten and then flow together forming the joint. A cast or over-heated grain structure is created in the immediate vicinity of the joint with a gradual gradation or change in microstructure back into the body of the metal until the point is reached where the temperature from the welding operation has not been sufficiently high to have any effect on the grain structure. Because of the high heat required to melt the edges, the intermediate metal has also reached a temperature that will cause an alteration in structure, the distance from joint to unaffected structure varying somewhat with thickness of the metal, speed of welding and cooling effect of jigs.

More will be said later about these other structures bordering the weld. A section

Various Structures in 0.10% Carbon Steel at 100 Diameters



through the joint in a tube made by a gas welding machine is shown at the left (weld at top).

The arc welding process also melts the edges, the joint generally being formed with the addition of extraneous metal (molten) from a welding rod or electrode, depending upon whether a carbon or metallic electrode is used. If the metal is thick the weld is formed by laying a succession of beads, the heat from each successive layer acting to anneal the previously laid bead. Such joints generally have the characteristic cast structure with nitride needles present within the weld. This has been shown by innumerable investigators, and need not be repeated here. Structure is altered adjacent to the melted zone; a sharp line of demarkation, very clear after etching, usually exists between the deposited and the base metal. Arc welding is most often done on heavier sections which retain the heat, consequently the base metal is annealed adjacent to the joint, and a zone of coarser grains is found next to this.

The third modern welding process, electric resistance welding, does not necessarily melt the edges of the metal, but generally raises them to the welding temperature only, the weld being consummated by means of pressure which is applied before, during, or immediately subsequent to the application of the current which generates the heat, the high temperature resulting from the resistance of the metal to the electric current. Some peculiar microstructures are found in "stationary" electric resistance welded joints (the process where the parts are firmly gripped in movable vises), but for the most part figure *d* of the group opposite can be considered as representative of the center of a resistance weld in low carbon steel, and of the early

resistance-welded tubes where the metal was unnecessarily overheated. The weld zone may appear to have dendritic crystals; one shown at *e* has signs of overheating, as the grains have become quite sharp. The gradation zone adjacent to the weld contains a diversified assortment of grain structures merging into one another.

There is a modification of the electric resistance butt-welding process controlled by Steel & Tubes, Inc., now extensively used for the continuous welding of pipe and tubing. This comparatively new practice and its unique metallurgical characteristics merit consideration. In carrying out this method, known as the Johnston process, the tube with butted edges is fed under a pair of roller electrodes at a comparatively high rate of speed. The factors which affect welding (such as time, temperature, and pressure) are so correlated that the heat is confined to a very narrow zone adjacent to the edge surfaces being welded (the weld is sometimes referred to as an "edge-surface weld") and only a small burr or flash is extruded. The composite photomicrograph on page 34 at 85 diameters shows a cross-section of a tube made of 0.060-in. strip by this process, showing both the extent of the heated area and the size of the upset. The microstructure is typical of this method of welding, and even when much heavier sections of 0.10% carbon steel are used the result is the same, for the relation of speed of welding and cooling is correspondingly adjusted. A description of the equipment and operation of the process was given in the first issue of METAL PROGRESS, September, 1930.

The question may be raised as to why there should be any intermediate structures in welded joints between the overheated metal and the base metal, outside of (1) grain

Section Through Tube Wall. Made by Oxy-Acetylene Welding Machine. Center of joint at top and unaffected metal at bottom; magnified 50 diameters

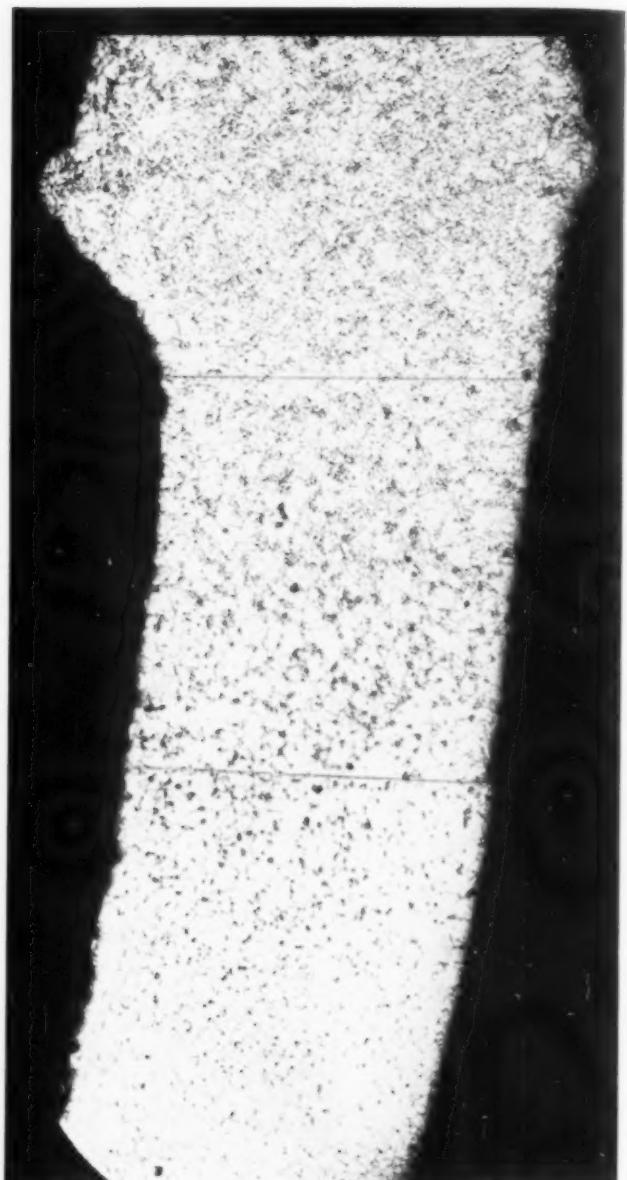
growth adjacent to the weld resulting from a combination of cold work (present in the steel from rolling and from forming) and a critical germination temperature, and (2) another adjacent zone of finer grains than present in the original steel, recrystallized by the heat conducted away from the weld into the base metal. This is generally true for welds where the metal is molten during the process and the sections are heavy. To some extent it is true for stationary resistance welds in thick sections. Things are not so simple in joints in light sections, nor is it characteristic of tubing or pipe welded by the electric resistance welding process, irrespective of the thickness of the metal.

When welding in light sections, independent of the process used, the cold adjacent metal has an accelerated cooling effect upon the heated zone and consequently a form of heat treatment takes place adjacent to the joint which accounts for the altered microstructure. A most unusual appearance is present in the gas weld shown on page 39, nearest the unaffected metal. It is like the metal at the very joint on page 34, and in the middle section of the view in the opposite column.

In the Johnston welding process the various factors are so combined as to limit the heat practically to the edge surfaces only. It follows that the ratio of heated area to total mass of cold metal is very small and the base metal exerts a rapid cooling action on the heated zone. The welding operation is performed at a speed in the neighborhood of 50 ft. per min. so that the joint does not linger under the electrodes nor does it retain the heat for a period longer than necessary to effect union. The surrounding atmosphere and the conveying rolls increase the speed of cooling, and, lastly, a stream of water is directed upon the weld during and after the welding operation so that the entire tube is virtually cold within 15 sec.

The net result should be a structure bordering the immediate weld zone representative of a heat treated steel (and this is to be expected since the tube is actually quenched).

The foregoing paragraphs deal with the structure adjacent to the weld, not the immediate vicinity where union has taken place. Let us now examine the locality where the original abutting surfaces have merged. Why does not



The Heat Treated Structure at Center of "Edge Surface Weld" Grades Back Into Original 0.03-In. Strip

this area, at least for a short distance, exhibit a cast or at least an overheated structure such as is present in other types of welding, since the welding temperature must necessarily have been over 2300° F.? (Compare the structure of the furnace butt-welded pipe, micro c of the first group, which was not heated as hot as is necessary for electric resistance welding, with the center of the upset on pages 34 and above. This whole area is composed of well-rounded grains of ferrite and sometimes fine black hair-lines, and a number of black spots dispersed through the ferrite.)

It has been erroneously stated that through some hitherto unknown means the carbon or

carbide has coagulated and collected and thus been increased in the weld zone. As a matter of fact, welding ordinarily has a tendency to de-carburize the metal at the joint. In edge-surface welding there is neither increase nor decrease in carbon content, as can readily be proven by normalizing the tube; this produces a structure at the weld which cannot be distinguished from the base metal.

The black areas are, as a matter of fact, sorbite or troostite containing an excess of ferrite. The structure is comparable to that developed in steel of the same analysis after an oil quench from 1600° to 1700° F.

The mechanics of the entire welding process is responsible for the evolution of this peculiar structure. A very narrow layer of metal is heated to the welding temperature in a fraction of a second, a speed which probably cannot be duplicated by any other heating medium or means, and at the same instant pressure is applied. The welded tube emerges from the rolls and cooling sets in immediately. The micro-structure cannot keep pace with the rapid heating, so to speak. Consequently the metal is already cooling before the structure has had time to approach that which we would expect to exist at the temperature momentarily reached.

We know that when treating alloy steels a soaking period is necessary to permit the atoms to migrate, but these soft steels have been heated so rapidly that even the carbon lags. Since cooling has begun before complete transformation or diffusion corresponding to the welding heat has occurred, the final structure is actually one which has been trapped by the cooling action as it is trying to catch up with the heat!

If it were merely an illustration of a quenching treatment after the structure had reached a state corresponding to the welding temperature, the final structure at the center would be either overheated or show signs of having been drastically quenched. Also, the application of pressure at the instant of welding (although undoubtedly of value in that it promotes grain refinement at the junction and in the upsets and also tends to minimize overheating) is not as important in the formation of the ultimate structure as one would assume.

For comparison, photomicrograph *e* is presented in the first group of a tube welded by an

obsolete continuous electric welding process. Considerably more heat was used and much bigger upset resulted; the speed of welding was also lower. Here the structure at the joint is characteristic of what might be expected, overheated and therefore somewhat brittle. The grains are much sharper and of totally different appearance from those in the center of welds made at high speed by the Johnston process. It is evident that the older resistance welds must have been hotter, or kept at temperature for a longer period or a greater mass of metal heated. It is ample proof that the physical characteristics of welds produced by the newer continuous electric resistance process should be better and more ductile.

Since the discussion so far has concerned itself exclusively with very low carbon welded tubing, it should be emphasized that the structures made by this new resistance tube welding process vary with the analysis, hardness, or gage of the original strip or skelp. Odd phenomena are frequently due to a difference in carbon content between the two edges of the original skelp when a body of ferrite with only occasional patches of sorbite butts into a mottled structure, half ferrite and half sorbite. One might be led to assume that a weld with this radical difference in grain structure in the weld zone would be unsatisfactory, but nevertheless this tube stood up under all tests. The crystals had actually merged across the original butted seam so flat that there is no zone of weakness in spite of appearances.

The ideal welded joint is one which is free from defects, one in which union has taken place between the original abutting surfaces, and one in which the microstructure has remained identical with the base metal. No process has been developed to date which will yield a weld to meet these specifications, but it is believed that present-day electric resistance welded joints in low carbon tubing and pipe are the closest approach to it. The joints, although slightly harder and of somewhat higher tensile strength than the base metal, still retain relatively high ductility and can be severely fabricated by hot or cold work without fracture. The microstructural characteristics, when closely examined, undoubtedly offer ample proof of the properties which may be expected.



CORRESPONDENCE AND FOREIGN LETTERS

PARIS, France.—THE International Congress of Electricity, held in Paris this year, is reminiscent of the Congress of 1881 (the influence of which was very great). It encourages us to cast a glance over the advances realized during these last 50 years by the electric industry, and their enormous repercussion upon all branches of human activity.

It seems opportune, on such an occasion, to point out the reciprocal influence that improvements in electricity and in metallurgy have had on each other. They have, indeed, common points.

In noting, first, the influence of electricity on the progress in metallurgy, we may single out first the progress in the knowledge of metals and alloys, and second the progress in fabrication and treatment.

Progress in Knowledge—In the laboratory, electricity has enabled us to take and record accurate measurements of all the properties of materials, since every physical measurement can be transformed into an electric impulse and the latter can be amplified and recorded. Moreover, the lighting and the heating of the equipment are electric, and all the apparatus created to study alloys (micrographic, thermal, dilatometric, resistometric, magnetometric, and auto-

Interdependence of Electricity and Metallurgy

matic apparatus for the study of hardening) have recourse to electricity.

Furthermore, the study of the electric properties (such as conductivity and its temperature coefficient, thermo-electric power, electromotive force of solution) and the magnetic properties of alloys, such as susceptibility, permeability, and so on (involving, as it did, an examination of many analyses and thermal treatments) has had a considerable share in increasing our knowledge about alloys. This knowledge was then used in the control of these materials. Purity of alloys and determination of elements in solid solutions have been controlled by means of conductivity and thermo-electric measurements; the carbon content in steels is rapidly controlled by magnetic tests; physical defects have been studied and internal stresses evaluated by magnetic, electric, and radiographic methods. Moreover, the development of X-rays has given us a powerful and valuable means of determining atomic and crystalline structure, and the influence of deformation or cold work upon related properties.

Progress in Fabrication—It is enough to mention the revolution accomplished by the electrothermic process (such as the use of the arc, resistance, or induction furnace for making pure metals, steel, cast iron, ferro-alloys and non-ferrous alloys, deoxidizers, and refractories) and by electrolysis, sometimes of fused baths,

C O R R E S P O N D E N C E A N D F O R E I G N L E T T E R S

whereby aluminum, magnesium, beryllium, and alkali metals are produced, or by electrolytic refining of copper, zinc, and the precious metals. Associated with the latter is the process of electroplating nickel, copper, chromium, cadmium, zinc, and many other metals and alloys. Lastly, the remarkable development of electric heating and of the electric control of rolling mills and other fabrication equipment has had an important influence on the accuracy of thermal and mechanical treatments, and on the economy of labor.

Looking at the matter from a different angle, it is at once apparent that a profound influence has been exerted by metallurgy on the progress of electricity. The latter has often depended on the metallic materials that were available. Copper and aluminum have so far been the best industrial conductors, but it does not follow that there is no chance to improve upon them. (In passing, sodium conductors, which are actually under test, may be mentioned.) Other collateral properties of conductors are also of importance; such as the superficial layer of alumina formed on the surface of an aluminum conductor by heating in the air or by electrolysis, which auto-insulates it. Conductivity and flexibility of these two metals are much influenced by their purity, and this has encouraged much study on oxygen-free and deoxidized copper. It is also possible to raise the rather low strength of aluminum by adding magnesium and silicon, and of copper by adding beryllium.

The opposite of conductivity is also important. Electric heating requires alloys having a very high and constant resistivity, a need which is supplied by solid solution alloys of nickel with iron, copper, chromium, or aluminum. Electric resistors also must resist oxidation, whence have come the various alloys of nickel, chromium, aluminum, silicon, cobalt, and iron. Incandescent lamps and the production of X-rays have required the development and use of refractory metals such as tungsten, tantalum, and molybdenum, and of iron-nickel alloys having correct thermal expansion.

Permanent magnets gained exceptional qualities after the properties of tungsten and cobalt steels were investigated. The permalloys and the permivars have been essential to modern communication systems. Silicon steel sheets accomplished a real revolution in the construction of dynamos and transformers.

While it would be possible to lengthen this list almost indefinitely, enough has been said to show the interdependence of the metallurgical and electrical industries, and the way many discoveries in the one art or science have immediately reacted on the other.

ALBERT PORTEVIN

PITTSBURGH — WHEN reading the paper by J. P. Gill and H. G. Johnstain on "Deep Acid Etch Test" in September METAL PROGRESS, I recalled that some years ago I presented some "Notes on the Manufacture of High Speed Steel" in *Chemical & Metallurgical Engineering* (March 15, 1922) in which were reported the results obtained when 1/64-in. disks of high speed steel

Composition of Carbide in High Speed

were immersed in a 10% nitric acid for a long time in order to separate the carbides from the primary austenite. These old results indicate the action was as completely selective as the etching of high speed steel in 1/1 hydrochloric acid, now reported by Gill and Johnstain, as results of both investigations are in very close agreement.

The thin disks which I prepared were made from steel of somewhat similar composition to that used by Gill and Johnstain, but the portion studied was cooled very slowly from the molten state in the crucible furnace and had absorbed considerable extra carbon. Analysis showed that the carbides or insoluble residue contained approximately 56% W, 3.3% Cr, and 1.5% V and that the metal in solution (originally the austenite) contained approximately 3.6% W, 3% Cr, and 0.74% V. These results are very similar to those reported in the paper by Gill and Johnstain.

CORRESPONDENCE AND FOREIGN LETTERS

In my efforts a complete chemical separation of carbides was attempted, whereas Gill and Johnstn were interested in showing the effect of selective deep etching.

J. W. WEITZENKORN

EAST PITTSBURGH, Pa.—IN THE JULY issue of *Transactions, A. S. S. T.*, my paper on "Solubility of Oxygen in Solid Iron" was published, which points out that gamma iron is liable to dissolve many times more oxygen than alpha iron will.

Since that was written more results in the same line have been obtained. Two 50-lb. ingots

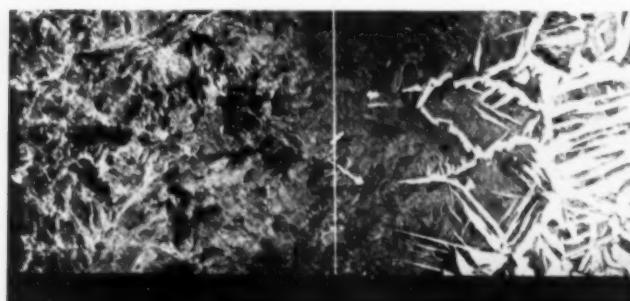
were prepared at the Westinghouse Research Laboratories in identical conditions by melting electrolytic iron in hydrogen atmosphere in an induction furnace.

Both ingots were forged to 3-in. hexagon bars, one at 850° C., the other at 1100° C. When analyzed for oxygen, the two ingots had identical analyses, namely, 0.013% O₂, 0.002% H₂, and 0.001% N₂. Carbon was 0.0021% and 0.0031% respectively. After forging, the bar worked at 850° C. contained 0.019% O₂, no hydrogen, and 0.003% N₂, whereas the bar worked at 1100° C. contained 0.081% O₂, 0.001% H₂, and 0.002% N₂.

This is a further confirmation of the results previously published, namely, that the affinity of gamma iron for oxygen is much stronger than that of alpha iron.

N. A. ZIEGLER

Hydrogenized (Oxygen-Free) Iron Is Perfectly Normal. 50 diameters



COLUMBUS, Ohio—DR. GROSSMANN in his letter printed in August METAL PROGRESS, page 46, appears to have conceded too readily (on the evidence cited by Duftschmid and Houdremont) that pure iron is abnormal. After reading this correspondence, I carburized at Battelle Memorial Institute a sample of high magnetic permeability iron very kindly supplied by Dr. P. Ciolfi of the Bell Telephone Laboratories. (This iron was vacuum-melted electrolytic iron, subsequently annealed in hydrogen at a high temperature, as described by Dr. Ciolfi in a recent issue of *Physical Review*.) As shown in the accompanying view, it was perfectly normal after carburizing 10 hr. at 1725° F. in a commercial carburizer.

I am inclined to believe that the iron described by Duftschmid and Houdremont contained enough oxygen to cause the abnormal structure. If the oxygen were reduced by annealing in hydrogen, the iron would very probably become normal.

SAMUEL EPSTEIN

COVENTRY, England—I WAS interested to read the discussion by O. W. Ellis on "Forgeability of Steel" in the September number. It represents a considerable amount of work upon the author's part.

No mention, however, is made of the condition of the anvil or pallet faces of the drop hammer. I presume that these were hardened and ground perfectly smooth and flat. This is important, as I have found, when making comparison tests between the blow of a 1000-lb. drop hammer and a friction screw press, that the condition of the surface of the pallet faces affects the results considerably.

The practical forge man would like a simple formula for finding out the size of hammer forging machine or press required to deform, flatten, or upset certain common shapes. This will require time and expense on some-

Condition of Dies Affects Forgeability

CORRESPONDENCE AND FOREIGN LETTERS

one's part, and the makers of forging equipment have a splendid opportunity for carrying out useful experiments in this direction.

F. W. SPENCER

TERIN, Italy — The remarks I made in my last letter (September) concerning our periodical metallurgical literature also apply to the Italian metallurgical books.

Notwithstanding the widespread knowledge of foreign languages among technical men in this country, and the relatively small number of factories in the metallurgical industries, properly so called, the number of books published annually is not negligible, and their sales nearly always cover the complete publishing expense. This means that 1000 to 1200 copies are sold, a number considered to be necessary, generally, to cover the cost of publication. In fact, there have been several recent examples of 2000-copy editions of special metallurgical books published in Italian that have been rapidly exhausted.

This rather unexpected fact is due mostly to their special character. Most of them are concerned especially with the finishing operations on metals and alloys (such as rolling, stamping, forging, heat treating, or cold working) so that they find more readers among metallurgists and supervisors in those plants that finish and use the special alloys than among the men who are engaged in the first stages of the smelting processes.

As I have pointed out in former letters, the mechanical industries are well developed in this country, and on account of the scarcity of cheap raw materials, they are obliged to specialize in the manufacture of high quality products, where the costs of the necessary raw materials have but a minor influence on the total costs of production.

Great efforts have been put forth in the last

few years in this direction, and the results have been generally very satisfactory. And as technical results are intimately connected with high quality and proper treatment of special alloys (both ferrous and non-ferrous) it is only natural that the men engaged in this effort are highly interested in this branch of metallurgical technique.

Many examples could be quoted. If we take the manufacture of ball bearings and roller bearings, we find that the Italian works are now producing ten times as much as six years ago, and exporting more than 80% of the production. One factory alone turns out more than 20,000 bearings a day, nearly all for export into industrial countries, where they have to compete in price and quality with the best products of the world.

Other industries, similar in their interest in the proper use of high quality special steels and alloys, have also shown similar developments under similar conditions. Such are, for instance, the manufacture of typewriters, of special tools, of sewing machines, of optical instruments, of gages and measuring instruments, of automobiles, airplanes and their motors and accessories. In all of these we find a great number of men directly interested in many phases of the science of metals, and they are the more in need of complete and up-to-date technical information in those branches, since the industries in which they work are in full development, and are making a great effort toward rapid technical improvement of the plant, process and product.

This serves to explain why — in a country like Italy, where the manufacture of iron and steel engages the attention of relatively few men and where the knowledge of foreign languages is widespread even among the workmen — metallurgical books can repay the publication expense.

FEDERICO GIOLITTI



CORRESPONDENCE AND FOREIGN LETTERS

RIDLEY PARK, Pa. — THE article on diffusion combustion by W. M. Hepburn printed in September leaves in my mind a reaction which says, "What do we know? and what do we know we don't know?"

To be specific, we have found that (a) raw gas in a metallurgical furnace heated by electric elements does not protect the ferrous materials sufficiently from oxidation; and (b) similarly,

Does Diffusion Combustion Need Free Carbon? in large forge furnaces using powdered coal, fuel oil, or natural gas, the degree of scaling and nature of the surface scale depend on the *time* of contact with the flame, and to no great extent on the character of the fuel being used.

Efforts to protect hot metal by a "smoky" flame have been made since the beginning, and it would appear that carbon immediately after being freed from a fuel gas should be active chemically just as nascent hydrogen and nascent oxygen are. In order to be effective in practical heating furnaces, the carbon—"nascent" if we may call it so—must be in considerable excess, as Mr. Hepburn states.

To accomplish such a result more fuel must be consumed. This costs money, and it is questionable whether it is money well spent, for, in the experience of hundreds of metallurgists, the deposition of any carbonaceous substance on ferrous materials increases the pickling time and requires a stronger acid.

So much for what we do know. Now for some things we do not know: Why is the gas blanket used in some instances and the diffusion principle (or, as I would term the process "retarded combustion") used in others? True, each application has its characteristic features, but isn't protection the same in either—or in any case?

Would we be correct in calling the net result

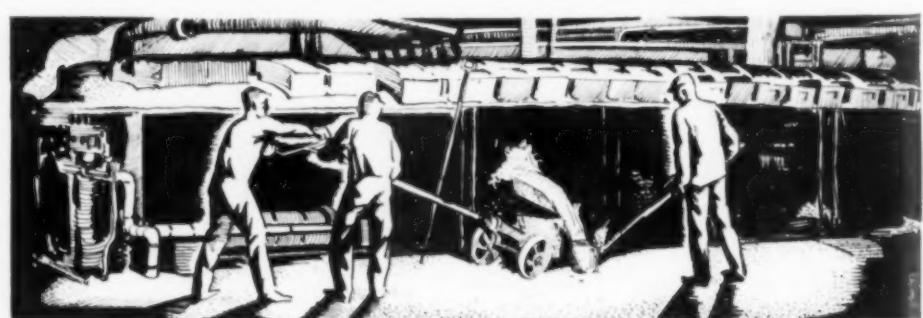
"diffusion combustion" if we used a gas with 18% H₂ and 28.5% CO and burned it with less than the correct air mixture for complete combustion, thus leaving 2 to 4% CO in the waste gases for protective value? Or suppose we used this same gas in a stream with one-half its volume of air, or even with enough air for complete combustion? In these cases, no carbon would be freed and the flames would be non-luminous in character—but incandescence would be achieved by virtue of the shorter lengths of light waves.

To my mind Mr. Hepburn's article stirs up a great deal for combustion chemists and engineers to think about.

ROLFE C. GOSREAU

SENDAI, Japan—If a piece of steel is heated above the A₁ point and quenched in water, a structure known as martensite is obtained. Its nature has recently been clarified by several scientists by means of X-ray investigations. Martensite is a solid solution of carbon in iron; the iron atoms have a body-centered tetragonal lattice, whose *a*-axis is a little shorter than that of alpha iron and the axial ratio *c* : *a* increases from 1.00 to 1.07 as the carbon content increases from 0 to 1.6%. According to views summarized by Dr. A. Westgren in METAL PROGRESS, August, 1931, the carbon atoms in martensite were thought to occupy positions within the space lattice of iron at points in the (001) plane, scattered here and there according to the law of probability.

Nature of the Two Martensites



METAL PROGRESS

CORRESPONDENCE AND FOREIGN LETTERS

About ten years ago, when the essential crystallographic nature of martensite was not well understood, two theories prevailed. The first was that martensite consists of a very fine dispersed system, the carbide particles being precipitated in a ferrite ground mass, and that the great hardness is due to slip interference. The second theory was that martensite consists of a solid solution of carbon in iron; hardness was explained by the combined action of lattice distortion, internal stress, and the fineness of the crystal grains.

Since then many important investigations have been made, and it has been now proven that martensite in a freshly quenched steel is a solid solution of carbon in iron. X-ray investigations show that the space lattice of martensite is body-centered tetragonal, the axial ratio of which increases linearly from 1.03 to 1.07 with the content of carbon. This can only be explained by the solid solution theory.

When such a quenched steel is tempered at about 250° F. for 30 min., the hardness slightly increases, the volume and also the electric resistance decrease, but yet the latter two properties are considerably greater than those of ferrite. Since this tempered substance resembles very much in physical properties the martensite formed on quenching, Dr. T. Matsushita considered it to be another kind of martensite. Thus we have two kinds of martensite — alpha martensite found in quenched steels and beta martensite in quenched and tempered steels. It has also been found that the lattice of the iron atoms in beta martensite is body-centered cubic, as in ferrite. Its lattice constant and the breadth of the spectral lines increases as carbon content increases.

About six years ago, one of the present writers showed by theoretical considerations that the A_{r_1} transformation consists, in its mechanism, of two successive changes; that is,

Gamma iron, dissolving carbon
→ alpha-like iron, dissolving carbon
→ ferrite + cementite

or, put in other words,

Austenite → martensite → pearlite. At that

time martensite was defined as a metastable intermediate product of the transformation. The above reaction needs a little modification to be applicable to the present conception of two kinds of martensites.

Since a face-centered cubic lattice may be regarded as a body-centered tetragonal one with an axial ratio $c/a = \sqrt{2}$ and since a body-centered cubic lattice may also be regarded as a body-centered tetragonal one with an axial ratio $c/a = 1$, the transformation from austenite to martensite may be supposed to take place very probably in the following way:

Tetragonal lattice ($c/a = \sqrt{2}$)
→ tetragonal lattice ($c/a = 1.03$ to 1.07)
→ tetragonal lattice ($c/a = 1$)

or, put in other words,

Austenite → alpha martensite → beta martensite.

In this view the mechanism of the austenite → martensite change is very simple; it is only necessary that the body-centered tetragonal lattice of austenite should contract in the direction of its c -axis and expand uniformly in perpendicular directions.

The simplicity of this mechanism permits such a complicated rearrangement of atoms as the change from the face-centered cubic lattice to the body-centered to occur during quenching.

In an accompanying contribution for *Transactions, A.S.S.T.*, we show reasons for believing that carbon atoms in austenite reside in the body-center of the elementary cube. During quenching, and subsequent transformation at 400 to 600° F., the carbon atoms cannot move far, and therefore assume the face-center of the (001) plane. Since that is not as stable as the $(\frac{1}{2}, \frac{1}{4}, 0)$ position, the carbon moves to it when the steel is tempered to beta martensite. We also show specific gravity computations, checked by experiments, to indicate that carbon does act as above, rather than form doublets and replace iron atoms in the regular lattice, as proposed by Öhman and Westgren in *METAL PROGRESS*, March and August, 1931.

KOTARO HONDA
ZENJI NISHIYAMA

X - R A Y D I F F R A C T I O N P A T T E R N S

SHOW STRAIN IN METALS

By N. P. Goss
Cold Metal Process Co.
Youngstown, Ohio

X-RAY STUDIES have given us a vivid picture of the arrangement of the atoms in crystals of pure metals, solid solutions, and chemical compounds. We know with amazing exactness the disposition of the atoms within the crystals. For instance, it is common knowledge that in alpha iron the atoms are arranged in a body-centered cubic lattice; this means that the elementary cell consists of 9 iron atoms, 8 of which are located at the corners of an imaginary cube and one at the center of the cube. In a single iron crystal this unit cell is considered to repeat itself indefinitely in three-dimensional space with the highest degree of precision and the atoms range themselves symmetrically on various sets of imaginary planes, equally spaced.

Such a configuration as described above would be a single *perfect* crystal. From the physicist's point of view, no perfect single crystals exist in nature. The diamond, however, approaches the specifications of a perfect crystal.

The term "molecule," so handy in elementary chemistry to describe the smallest

stable unit of reaction, has little or no meaning when applied to the structure of crystalline solids. Sometimes the word is used to mean the number of atoms required to build the unit cell. In alpha iron, each of the eight corner atoms is shared by eight cubes touching that point; the center atom belongs to one cell exclusively. The "molecule" therefore contains two iron atoms. For complex structures such as iron carbide it is a very tedious task to determine the number of atoms in the unit. An instance was given by Dr. Honda in a letter to METAL PROGRESS in November, 1930.

To illustrate how the geometrical arrangement of the atoms determines the physical properties of a substance, consider the element carbon, the building stone of both graphite and the diamond. How can mere arrangement cause such diverse physical properties?

Dr. Bragg describes in his "Introduction to Crystal Analysis" how he discovered, with the aid of the X-ray spectrometer, that in the diamond the carbon atoms are equally spaced in all directions and that the elementary cell is a tetrahedron. This means that the bond strength between atoms is the same in all directions; therefore, this crystal possesses no direction of weakness in which plastic deformation can take place. It is also logical to believe that the hardness of the diamond is due to the uniformity of strength and resistance to deformation in all directions.

While graphite is also composed of carbon atoms and crystallizes in the hexagonal system,

it is made up of atomic planes on which the atoms are arranged in a hexagon. These laminations or atomic planes of carbon atoms are equally spaced and the spacing between these laminations is great in comparison with the distances between the atoms which lie in the plane of the laminations, and the latter can glide one past another with great ease, because of the great atomic distances between the successive laminations. This explains why graphite is such a splendid lubricant.

The spiral arrangement of the silicon and oxygen atoms in quartz explains some of its remarkable optical phenomena. While many such relationships can be deduced from a knowledge of the geometrical configuration of the atoms, much more will be revealed when we know more about the nature of the atom itself, its electrons and their distribution within crystals or grains, and the structure of the proton or nucleus of the atom. Our present conception is that the protons occupy the lattice points and the electrons revolve about them in a planetary motion. Electrons appear to be in kinetic equilibrium only when they occupy appropriate orbits. When an electron jumps from one orbit to another, energy is radiated or absorbed as the case may be.

The structure of the proton or atomic nucleus is unknown. Experiments in optical spectroscopy indicate that the nucleus rotates and revolves in an orbit of its own. In addition to the orbital motions of the electrons they may also under certain conditions possess a kind of spin. This idea was introduced to explain "ortho" and "para" hydrogen; the structure depends on whether the electron spin was left or right handed. This phenomenon also is supposed by some to explain magnetism in magnetic substances.

Those more interested in this matter may consult Sommerfeld's "Atomic Structure and Spectral Lines" published by Methuen & Co. They will find that the general idea of the construction of atoms proposed by Bohr accounts very beautifully for the X-ray spectra of the elements, but it does not explain other optical and radiation phenomena. Consequently, the "Bohr atom" has been considerably modified by research physicists. Each day brings new experimental facts concerning the structure of matter

and these support or refute previous notions.

This brief outline reveals the complexity of matter and how little we know about it.

What has this to do with metallic grains? Are not all grains of steel, copper, and aluminum composed of atoms and molecules? When a specimen of steel is examined under the microscope, does it really show the internal structure of the grains? Is it sufficient to say that a piece of low carbon steel is annealed when the grains appear equiaxed and the physical tests are at a minimum?

Everyone engaged in physical testing has at some time or other found lots which met the requirements during processing while another failed, yet the physical and chemical tests were practically the same.

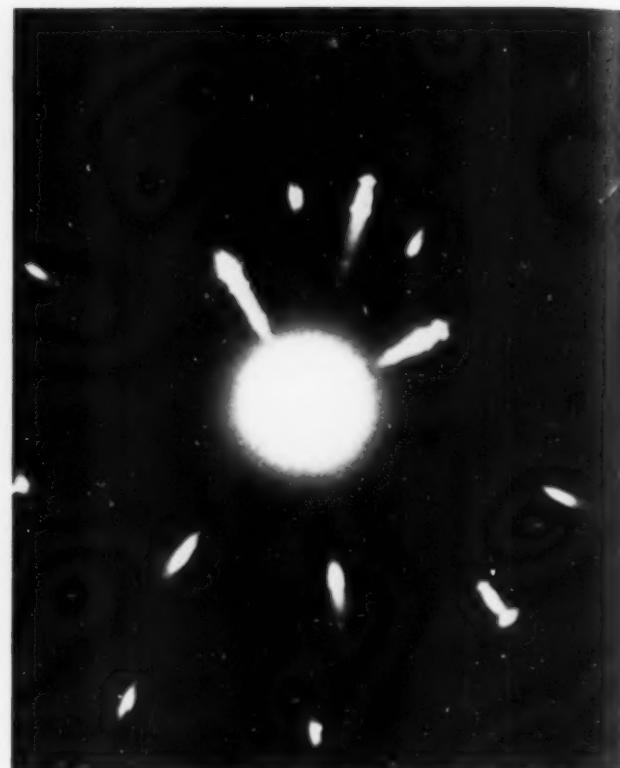
In order to find the differences in these materials, indistinguishable by less powerful tests, the modern investigator turns to X-rays. They have already determined the arrangement of the atoms in crystals and from this alone, certain physical properties could be explained, or (if unknown) predicted.

Even though a single *perfect* crystal such as described by an X-ray lattice seldom exists in nature, a high degree of perfection can be attained in commercial materials under the proper conditions.

The X-ray reveals the internal structure of the matrix of pure metals, alloys, or compounds regardless of their complexity. Even though the information is only of a qualitative nature, by preparing standards of the various metals and alloys for comparative purposes and making X-ray diffraction patterns under exacting conditions, a surprising amount of information can now be obtained.

It should be mentioned that it is of little if any value to prepare one X-ray diffraction pattern of some material that failed. The real value of the method will only be realized when a systematic search is made. This requires patience, skill, and an ever increasing number of carefully prepared specimens about which a great deal is known.

Many splendid contributions about precise X-ray diffraction methods have already been made by various investigators and their papers should be consulted by those interested in the matter. A good start can be made in Jeffries



& Archer's volume "Science of Metals," and the article by Prof. McKeehan in METAL PROGRESS in June, 1931. Refer also to "Study of Grain Structure of Martensite" by Heindlhofer and Bain, *Transactions, A.S.S.T.*, 1930; "X-Ray Metallography" by G. L. Clark, *Metals and Alloys*, July, 1929; and "Orientation of Crystals in Rolled Metal" by Davey and others, Technical Publication No. 243, A.I.M.E.

What does an X-ray pattern of a single crystal of great perfection look like? The first photograph shows diffraction spots surrounding the central beam passing through a single crystal of low carbon steel. It reveals near perfection, since the atomic planes in corresponding families are parallel each to each throughout the entire extent of the crystal.

In contrast is a second figure—an X-ray diagram of what was believed to be a perfect single crystal of low carbon steel. Actually, the structure was distorted. Diffracted rays, instead of converging on a number of small points, diffused themselves along radial lines. When an annealed crystal grows with such a distorted structure there must be a reason for it.

Grain distortion has nothing to do with lattice distortion. Grain distortion is only concerned with the disposition of the atomic planes,

Diffraction Patterns of Single Crystals of Low Carbon Steel Give Qualitative Measure of Perfection in Structure. At left is one where the atoms are at exact positions; above is from a distorted structure

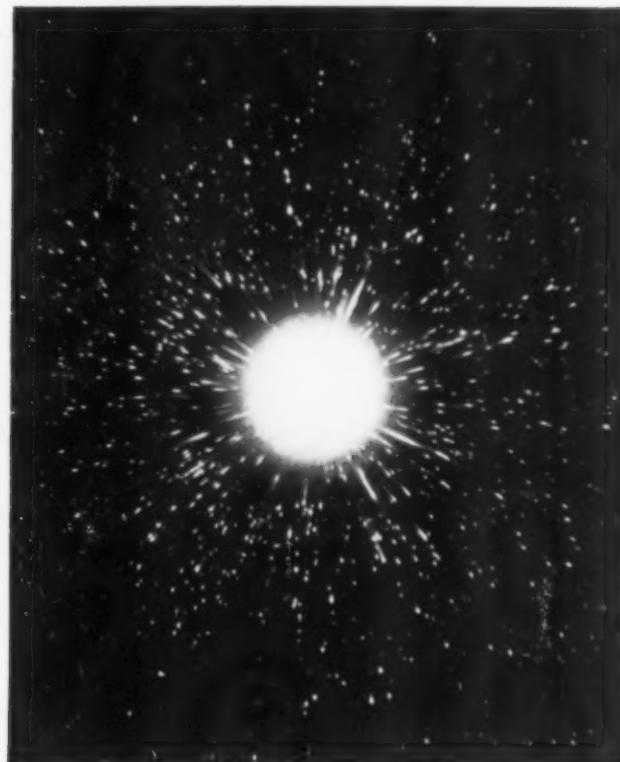
just as lattice distortion is concerned with variations in the distances between successive planes in a single crystal. Grain distortion occurs when a piece of metal is severely cold worked. Lattice distortion occurs when a second element is taken into solid solution.

What is true of large single grains is also true of crystal aggregates. Two instances are shown opposite, one an X-ray exposure of an aggregate of small crystals, each of nearly perfect structure, and another exposure of distorted crystals. The physical tests for such structures would be the same. On the other hand, it is well known that some strip or sheet steels having similar Rockwell hardness numbers and Erichsen cup test will deep-draw while others fail. This was pointed out clearly by papers read by E. S. Lawrence and by E. V. Crane before the Boston convention, A.S.S.T., last year. The internal or atomic structure of these materials must be studied and then and only then will the importance of such things as annealing time and heating rate be appreciated.

There are scores of other cases where simple X-ray diffraction diagrams could be of greatest



Same Indications Hold to Aggregate of Small Crystals, Such as a Piece of Commercial Metal. At left the crystals are not distorted, at right they are. Large central spot is halation from the undeflected X-ray



value in metallurgical research problems in which matrix structure is most important.

Several recent contributions show that stresses exist in plastically deformed crystals. Joffe and Kripitcheva used single crystals of rock-salt which were gradually compressed. An X-ray beam was transmitted through the crystal as it was being stressed and the effects observed directly on a fluorescent screen.

Below the elastic limit of the material no changes could be detected in the diffraction spots, but when it was exceeded the diffraction spots could be seen to elongate and the direction of slip could be determined. The luminous spot due to the reflection of the X-ray beams from the (110) planes remained completely unaltered; all the others were elongated, and the greater the loading the more pronounced were the radial elongations. From these observations the investigators concluded that the grain fragments slipped or glided on the (110) planes by a translation and a rotation. The lattice dimensions of the strained and unstrained crystals were found to be the same.

They tried the same experiment on quartz

and found no changes on the fluorescent screen until the ultimate strength was passed. They therefore concluded that the elastic limit and ultimate strength coincided. It can be seen that investigations of this nature, using photographic plates for a record, would be very useful in the determination of the elastic limit of metals by direct observation.

This method would hold for single crystals, but experiments by the writer on crystal aggregates show that (as might be predicted) the elastic limit is not reached by each crystal at the same time. Some crystals may have reached the yield point while others are just exceeding the elastic limit. This is of prime importance in deep drawing metals and illustrates the importance of uniformity in the internal structure of the grains.

One more industrial opportunity of great promise is in the study of wire. Schmid and Wasserman, for example, find that the fiber of severely drawn fine grained wires is more perfectly developed in the interior axis of the wire than at the skin. Tensile tests on the drafted wires compared with those having the skin removed by etching also indicate that the core of the wire is stronger. Similar results were obtained by the writer on wires drafted 99½%.



CONCENTRATES FROM THE LITERATURE

MONTHLY pamphlets are issued by the Newark (N.J.) Museum called **DESIGN IN INDUSTRY**, which annotate the chief literature in that field. Recent issues indicate an abrupt drop in interest in color as a factor, but an increase in articles relating to the heavy industries. Subscription is \$2 a year.

TABLES of Cubic Crystal Structure" (including lattice dimensions of elements, chemical compounds, and alloys) is the title of a 90-page bibliography published by Adam Hilger, Ltd., London, N.W. 1, at 11s 6d. Its value has been appraised in a foreword by Dr. Bragg: "The length of this summary is its own justification, for it shows how much searching of journals is required to discover whether or no any particular substance has been examined."

SCORING of brake drums has been intensified by high speed and heavy cars. According to F. L. Main (*S.A.E. Journal*, August) this is mainly due to ferrite crystals, dragged out of the drum and embedded in the lining. The simplest way to correct it is to produce drum surfaces with no free ferrite. This can be done in steel by alloying, by carburizing, or by heat treating, but these are expensive expedients. Success of **CAST IRON DRUMS** on heavy trucks and busses has led to the development of pearlitic cast iron drums, either sand cast, or centrifugally cast inside hot steel shells. The final microstructure is most important, and should have well-developed pearlite, no ferrite, and

finely dispersed graphite. Chemical composition and cooling rate must be mutually adjusted to secure this pearlitic cast iron, which will have a tensile strength of 40,000 lb. per sq.in. and Brinell hardness of 200. He recommends an iron with 3.3% total carbon, 2.25% Si, 0.25% Ni, 0.50% Cr, cast at 2800° F. into a red hot shell spinning at 1100 r.p.m. The iron and mild steel interpenetrate for about 0.01 in., making a strong weld.

THE most widely used cyanide hardening steels are S.A.E. 1112, 1120, and 1020, and high-manganese free-machining steel for small low-strength parts with high wear resistance. Ductility and freedom from distortion may be increased by heating in an oven or neutral bath to 1550 to 1600° F. and quenching in oil before the cyanide treatment, a method discussed by W. Paul Eddy, Jr. in a pair of articles in *The Iron Age* on **HEAT TREATING BATHS** (Sept. 15 and 29). Certain highly stressed parts of medium carbon alloy steel, such as gears, may also be given maximum wear resistance in case hardening baths. The ideal salt bath should be inert, stable in composition, thinly fluid at operating temperature, non-hygroscopic, should clean easily, and should not form a sludge, fume corrosively, nor pit the work or container. Such a salt is as yet unknown but those now in use give good results if narrow temperature limitations are observed. Extravagant claims made for salt mixtures during recent years have made users somewhat wary and have discouraged progress in this direction.

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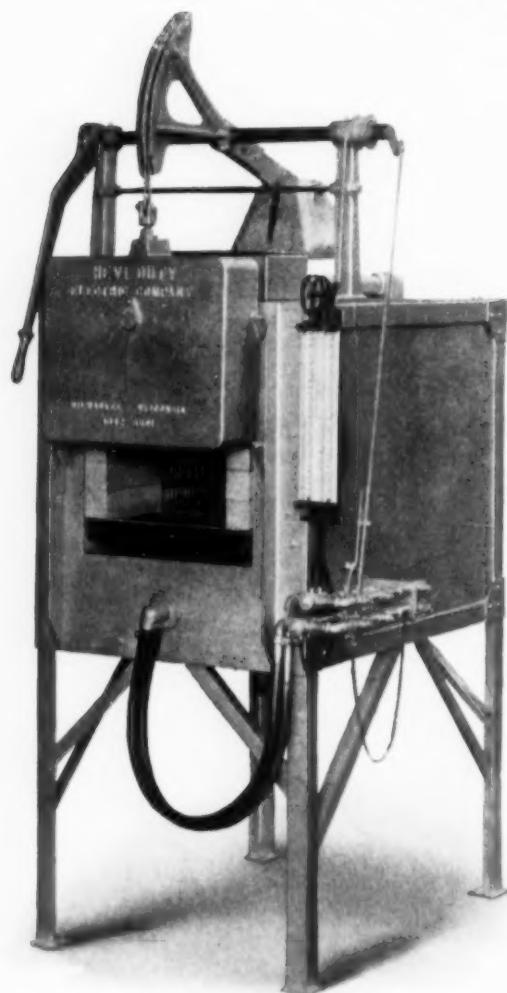
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HEAT TREATING FURNACES

IN VIEW of the interest shown in England about compressed coal gas for motor truck fuel, some experiments on thin-walled containers were made by F. S. Marsh (British Iron & Steel Institute, September meeting). **GAS CYLINDERS** of 0.30% C steel were made, having 2.6% Ni, 0.7% Cr, and 0.4% Mo. Billets were punched and drawn hot over a mandrel into 7½-in. tubes. They were softened at 1200° F., machined inside and out to a 0.2-in. wall. Both ends were swaged to hemispheres, fitted with screw connections; the cylinders were then air hardened from 1560° F. and tempered at 1110° F. Hardness was 280 Brinell. Metal from the wall had 132,000 lb. per sq.in. ultimate, 108,000 yield point, 17.5% elongation in 2 in. Longitudinal impact was 14½ ft-lb., transverse 4. Stress in the cylinder walls at 3000-lb. gas pressure is about 57,000 lb. per sq.in. Pressure tests indicated uniform elastic movements up to 50% overload. Bursting by splitting (no fragmentation) occurred at about 6700 lb. pressure. Rough handling, simulating collisions at 30 miles per hr., caused only local dents; rifle bullet perforations caused no splitting. The author concludes that high-pressure light-weight low-alloy steel cylinders can be manufactured with uniform quality, able to withstand wrecks or abuse.

HEADLAMP shells are stamped from 0.025-in. gage 18-8 rustless steel at the Ford plant at Flat Rock, Mich., in presses which perform eight operations and turn out 18 lamps per min., according to Burnham Finney in *The Iron Age*, Aug. 11. One operator is required to load the **STAINLESS STEEL** disks in the magazine. Oiling of the stock, first and second draw, trim, final draw to a depth of 4 9/32 in., forming the flange in four successive dies, and delivery to a belt conveyor are all automatic operations. The lamp rim, of low carbon strip, cadmium plated, is spot welded to the shell. Two reflector lugs are embossed and the door spring flange formed on small presses, after which the lamps are inspected and automatically polished and buffed. The door frame is made separately of rustless strip steel welded onto a

CONCENTRATES

round rim. On another machine it is expanded to proper diameter and the flash trimmed. It is then washed, pressed to final shape, and polished and buffed. Reflectors are brass disks plated with nickel and then silver. Tail lamps go through a similar process except that forming the hub on the angle hole is a severe operation requiring spot annealing.

A CONSIDERABLE amount of silicon structural steel was used in the St. Johns bridge at Portland, Oregon, a suspension bridge with 1207-ft. center span. This bridge also is the longest to use twisted strands (pre-stressed) in place of parallel wires for the main cable. Increased efficiency of the SILICON STEEL may be gathered from an article by D. B. Steinman, the designer, in *Journal of the Franklin Institute* for October, wherein he states that the silicon steel chords of stiffening trusses will be stressed to 32,000 lb. per sq.in. under the most extreme combination of loads, whereas the medium carbon steel in diagonals will be stressed simultaneously to 26,000 lb. per sq.in. Working stresses in tension for the carbon steel structural shapes in hangers and floor beams are 18,000 lb. per sq.in., whereas the silicon steel plates in the anchorage chains work at 24,000 lb. in direct tension.

A NEW process for making welded joints is described by H. S. George in *Journal, American Welding Society*, July. It is a SELF-FLUXING WELD in the sense that a flame with excess acetylene not only reduces oxide scale on the base metal but carburizes the hot solid steel surface to a depth of 0.001 to 0.002 in. to eutectic composition. This surface film melts at 2100 to 2200° F. and is dissolved by liquid metal from the welding rod, and the latter gains access to clean base metal beneath and unites with it in a true weld. The new process is metallurgically similar to soldering and brazing in that there is a minimum of inter-diffusion of base metal and filler metal, but entirely dissimilar in the fact that the joint

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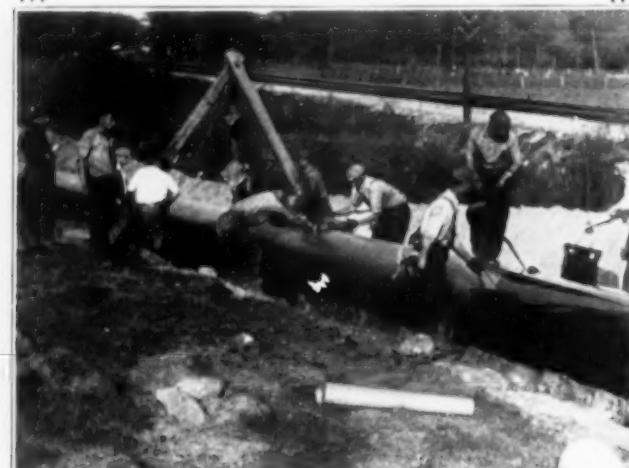
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cannot be loosened by heat. Comments on the process were made editorially in *METAL PROGRESS*, November, 1931, and illustrations of the equipment and its achievements in pipe-line welding in an article by G. O. Carter last May. Mr. George says that bend ductility of 15% is ample to denote sound weld metal and toughness in ordinary firebox steel; self-fluxed welds will stretch 20% in outer fibers, and 10% if normalized. Butt-welds "as welded" have outpulled 90,000-lb. plate. He also notes the ability to make heat treatable joints in aircraft chromium-molybdenum sheet and thin-walled tubing, testing 125,000 to 150,000 lb. per sq.in. and breaking 3 to 4 in. from the edge of the joint.

BABBITT vs. bronze was discussed by C. H. Bierbaum in *Machine Design* (September) and by J. B. Fisher before the Chicago Section, S.A.E. Lead-base babbitts are for the lightest service; tin-base for medium heavy. Hard particles of a bearing should be in the hardness range of the shaft, so the two will polish each other. Hence babbitts are used with softer steels, bronzes with harder. For heavy service at high temperatures solid bronze should be used (copper-tin, copper-lead-tin, copper-tin-nickel-lead). Mr. Fisher said that expert workmanship and highest grade tin-babbitts are required for heavy-duty engines, otherwise the bearing surfaces rapidly embrittle at the ends. He recommends copper-lead bearings for truck engines, especially for desert service, where temperatures of 320° F. in the oil pan have been measured. Copper-lead bronze has three times the heat conductivity of the tin-babbitts, it is considerably stronger even at 70° F., and its melting point is far above any possible oil temperature.

IMPACT extrusion of aluminum, discussed by H. H. Hall in *American Machinist* for Aug. 17, is a faster process than the older hydraulic extrusion and is usually done cold rather than hot. It is a squirting operation in which a flat slug of annealed metal is held in a shallow, cup-shaped



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die and compressed by a punch so the metal flows upward to form the walls of the shell. The severe cold work of **IMPACT EXTRUSION** hardens and stiffens the product. Heavy machinery using strong steel is required for impact extrusion, but it is generally cheaper than drawing equipment since only one operation is necessary and only one set of tools is required, the shell proportions being varied by changing the gage of the blank. The ratio between length and diameter of the shell determines whether drawing or extrusion is most economical, shallow shells being more cheaply made by drawing than by extrusion. For extrusion this ratio should be greater than $1\frac{1}{2}$. Rectangular and oval cans may be impact extruded as easily as cylindrical ones, and such modifications as bosses, lugs, rivets, stems, necks, indentations, or embossed figures may be formed on either the outside or inside of the closed end. The sides, of course, must be smooth. The Hooker process for tubing is a modification of impact extrusion in which the metal flows down rather than up.

RECENT investigations made for the Copper & Brass Research Association and also by W. H. G. Vernon (British Institute of Metals) have shown that the natural green patina formed on copper is a basic copper sulphate rather than a chloride or carbonate as previously supposed. Dr. Vernon has formed an artificial **PATINA ON COPPER** by an anodic treatment of 15 min. in a suitable electrolyte, and also by treatment with ammonium sulphate. The latter method, as developed by the Copper & Brass Research Association, is described by John R. Freeman, Jr. and P. H. Kirby in September *Metals & Alloys*. The copper to be colored is alternately immersed in a 10% solution of ammonium sulphate at about 140° F. and exposed to the atmosphere. This treatment continued for 21 hr. will produce a coating very similar in composition to that formed after 12 to 14 years exposure to weather. The color is a dark blue-green which may be changed to the lighter green of the natural patina by immersion in hot water for about half an hour.

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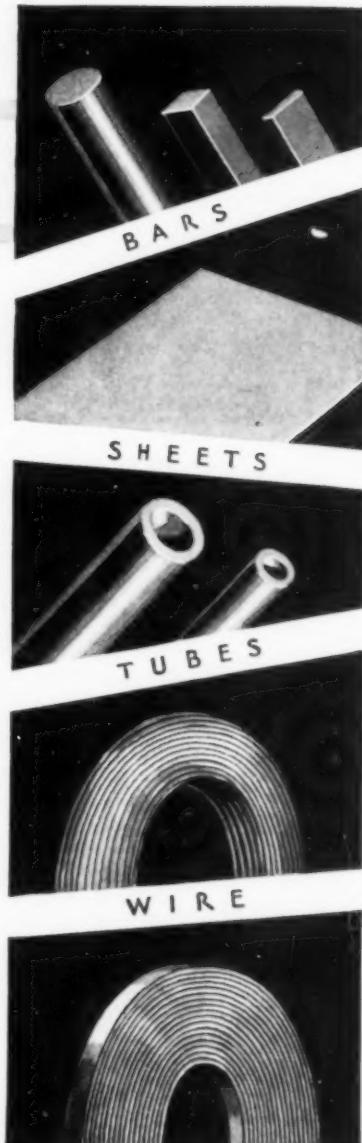
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HARDENABILITY

(Cont. from page 21) be a vastly more important factor in determining hardenability than dissolved oxygen. It is our thought that this is true, but that oxygen is still a factor.

The ideal way to maintain a fine austenite grain would be to disperse in the steel a system of fine oxide particles. Accordingly, we have been inclined to accept the hypothesis of those who have suggested dispersed alumina as one cause of fine grain and abnormality. If the particles, which are to act as a grain-growth inhibitor, are to be formed *in situ* in the molten steel, then the steel must contain sufficient oxygen to combine with the needed amount of alloy and no substantial coalescence must occur; neither requirement is incompatible with effective practice.

Direct experimental inquiry into the existence and nature of minute particles, which, to be most effective, must remain practically submicroscopic, seems at the moment impossible, but a few more or less indirect observations may be considered.

A series of pure iron-aluminum alloys was prepared. When such alloys carrying more than about 0.4% aluminum were carburized in hydrocarbons, the structure was highly normal throughout, as shown on page 21. In contrast, when pack-carburized, they developed a very fine-grained, abnormal structure in the outer portion of the hyper-eutectoid zone, further characterized by a shower of fine particles, shown in the last figure, which we assume to be alumina — entirely absent in the specimens

carburized in hydrocarbons. Inside this zone the two methods of carburizing produced identical normal structures.

We interpret these observations as indicating the alumina particle inhibition to grain growth by the combination of aluminum (contributing itself toward normality) with the oxygen introduced in carburization. The aluminum combined so vigorously with the oxygen that only a shallow layer was affected; the higher the aluminum content the thinner the surface zone of abnormality. We are therefore persuaded that the usual small additions of aluminum contribute to shallow hardening, but solely by grain growth inhibition offered by the dispersed insoluble alumina particles.

After a discussion of the structures found in plain carbon tool steels, Dr. Bain summarized his propositions, first, that hardenability depends upon the actual rate at which its austenite transforms to fine pearlite; and second, that this rate depends upon its composition and its effective grain size. The finer the grain size, the more rapid the transformation and therefore the lower the hardenability. He ended with the following challenging questions:

"1. May it be that the primary influence of any element (including oxygen) in true solid solution in austenite of a specified grain size is to retard the rate of transformation and hence to favor deeper hardening?

"2. May it be that the main effective contributor to shallow hardening is oxygen combined with elements such as aluminum and vanadium in the form of a fine dispersion of insoluble particles?"



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